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PRINCIPLES

OF

HUMAN PHYSIOLOGY.

The following are extracted from among the numerous testimonials of the medical press, in favour of

CARPENTER'S HUMAN PHYSIOLOGY.

"Dr. Carpenter's work is, in particular, much better adapted to the medical student than any other of the kind we have met with, inasmuch as its plan has a direct reference to medicine; and the bearings of physiology on the various branches of that science and art are set forward in a philosophical and lucid manner.

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"Numerous as are the works on Physiology which have of late issued from the press, a volume was still much wanted which should serve as the hand-book and text-book of the medical student. 'The Principles of General and Comparative Physiology' of Dr. Carpenter, which have just entered upon a new edition, and which we have had occasion to mention with commendation in our last volume, had already opened the path to the extension of the labours of that author into the more important department of human physiology. The able manner in which the subject of comparative physiology was handled, the enlarged and elevated views entertained by the author, at once pointed to Dr. Carpenter as the writer by whom the obvious want in the field of human physiology was to be supplied. The volume before us is the much-desired contribution to our science for which we have long looked.... In concluding our notice of this volume, we do so by recommending it most strongly to our readers, and especially to our young friends, who are preparing a foundation upon which to build their reputation and future success in life. The volume is beautifully got up; it will form an ornamental addition to the study and library."—*Lancet.*

"The 'Bristol Medical School' is fortunate in having such a Lecturer as Dr. Carpenter, whose most elaborate and important work now lies before us.... We have been anxious to bring this work as early as possible before our readers, not pretending to give them any of the information which it contains, but merely pointing out to them the abundant fountain whence they may draw for themselves."—*Med. Gazette.*

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"As a scientific work, it places the reader in possession of the knowledge acquired to science by the most modern as well as most ancient physiologists. As a work of art, we cannot too much commend its composition, enhanced as it is, by many beautiful illustrations."—*Provincial Med. and Surg. Journal.*

PRINCIPLES

OF

HUMAN PHYSIOLOGY,

WITH THEIR CHIEF APPLICATIONS TO PATHOLOGY, HYGIÈNE, AND FORENSIC MEDICINE.

ESPECIALLY DESIGNED FOR THE USE OF STUDENTS.

WITH OVER ONE HUNDRED ILLUSTRATIONS.

BY

WILLIAM B. CARPENTER, M.D.,

LECTURER ON PHYSIOLOGY IN THE BRISTOL MEDICAL SCHOOL, &c.

FIRST AMERICAN EDITION, WITH ADDITIONS BY THE AUTHOR,

AND NOTES AND ADDITIONS,

BY

MEREDITH CLYMER, M.D.,

LECTURER ON THE INSTITUTES OF MEDICINE, PHYSICIAN TO THE PHILADELPHIA HOSPITAL, FELLOW OF THE COLLEGE OF PHYSICIANS, &c.

PHILADELPHIA:

LEA & BLANCHARD.

1843.

T. K. & P. G. Collins, Printers.

TO

WILLIAM PULTENEY ALISON,

M.D., F.R.S.E., &c. &c.

PROFESSOR OF THE INSTITUTES OF MEDICINE IN THE UNIVERSITY OF EDINBURGH.

My Dear Sir,

I take the liberty of inscribing the following Work to you, as an expression of my grateful remembrance of the value of your instructions, of my respect for those intellectual faculties which render you pre-eminent amongst the Medical Philosophers of our time, and of my admiration for those moral excellencies which call forth the warm regard of all who are acquainted with your character.

In many parts of this Treatise, you will find that doctrines, which you have long upheld in opposition to almost the whole physiological world, are defended with such resources as I could command; and that, in many instances, such convincing evidence of their truth has been afforded by recent observations, that further opposition to them would now seem vain. And if I have presumed to differ from you on some points, it has been in the spirit of that independence which you have uniformly encouraged in your pupils, yet with a distrust of my own judgment wherever it came into collision with yours.

That you may long be spared to be the ornament of your University, and the honour of your City, is the earnest wish of,

Dear Sir,

Your obliged Pupil,

William B. Carpenter.

Bristol, Feb. 1, 1842.

PREFACE.

The composition of such a Treatise as the following was a part of the original plan of the Author, when he first came before the Public as a writer on Physiology. Being desirous, however, of making his first essay in the path which had been previously the most incompletely explored, he deemed it better to await the verdict upon this before proceeding further; and he was not without hope, that some writer, more fully competent to the task, might in the mean time take up the subject of Human Physiology in such a way as to leave nothing for the Student to desire. This, however, has not been accomplished. The previously-existing Treatises upon it, which have been every year becoming more antiquated, have not been replaced by any works that can be considered as at the same time sufficiently elevated in their character to represent the present condition of Physiological Science, sufficiently compendious in their bulk for the limited time at the disposal of most Students, and sufficiently practical in their tendency to lead their readers to the useful applications of the facts and principles they place before them. This is not the opinion of the Author alone, but that of numerous experienced Teachers throughout the country; and he has been led to regard the present as a good time for carrying his purpose into execution.

The plan and objects of his Treatise may be gathered from the preceding statement of the reasons which have occasioned its production. In this, as in his previous work, it has been his object to place the Reader in the possession of the highest principles that can be regarded as firmly established, in each department of the Science; and to explain and illustrate these, by the introduction of as many important facts as could be included within moderate limits. In every instance, he has endeavoured to make his statements clear and precise, without being formal or dogmatical; and definite enough to admit of practical application, without appearing to be unimproveable by further inquiry. Physiology is essentially a science of progress; and it must happen that much of what is now regarded as established truth, will need great modification to be brought into accordance with the results of new inquiries. It is very desirable,

therefore, that the Student should not be made to think so confidently of his acquirements, as to be indisposed to receive new information, even though it should tend to diminish their value. There are several departments of the science which are, at the present time, in what may be termed a transition-state. Such may be said of the Physiology of Nutrition, which is fast emerging from the deepest obscurity into clearer day; and, as might be expected, there are several questions which can scarcely be at present regarded in any other than a very doubtful light. The Author is not without hope, that, in several parts of his Treatise, suggestions may be found, that will lead some of his Readers to original researches on the numerous topics to which they refer; and he considers that he will be thus doing greater service to the public, than if he were himself to aim at embracing the whole range of inquiry thus indicated. With these views, he has not hesitated to express uncertainty where he has himself felt it; and he trusts that what he has thought himself justified in stating with more positiveness, will thus be entitled to greater weight. On one point,—the distinct existence of the grey fibres constituting the Organic system of Nerves,—he deems it right here to say, that the text (§111) expresses a greater degree of certainty than it would be probably right to assume, on a question at present so controverted. The fact is, that there is so strong a resemblance between these fibres, and those of ordinary fibro-cellular tissue, that it is not easy to distinguish them; and there are many able Microscopists who affirm that they are really identical, whilst others are as positive of their distinctness. To the Author himself, it appears that a strong argument from analogy may be drawn in favour of their existence. In the coats of the arteries and some other structures immediately connected with the Organic Functions, there is a kind of substance resembling ordinary fibrous tissue in appearance, but having many of the properties of the Muscular fabric. It can scarcely, then, be deemed improbable that, in the parts of the Nervous system which are specially destined to influence the Organic processes (if such there be), a similar departure from its regular type, and an approximation towards the ordinary fibrous texture, should manifest itself.

The present Treatise is to be regarded as complete in itself, and as quite independent of the Author's "Principles of General and Comparative Physiology." That it may be so, he has inserted an introductory chapter on the "Place of Man in the Scale of Being," and numerous references to the Comparative Physiology of the lower Animals. Still he does not hesitate to express the opinion that, the greater the amount of the Student's previous general knowledge of

the Science, the better will he be prepared to enter upon any department of it, especially that peculiarly complex and difficult branch, the Physiology of Man. On every topic, it has been the Author's aim to present the latest and most satisfactory information within his reach; and he believes that the Volume contains much that will be new to the Physiologist, whose reading has not been tolerably extensive. Its materials have been but little derived from other Systematic Treatises on the subject; and it will not be found to bear, as a whole, any considerable resemblance to those already before the public. The Author has rather endeavoured to bring together the valuable facts and principles, scattered through the best of the numerous Monographs, that have been recently published on special divisions of Physiology and Medicine; and to reduce these *disjecta membra* to that systematic form, which they can only be rightly made to assume, when brought into relation with each other, and shown to be subservient to principles of still higher generality. To the following Treatises and Memoirs he may especially refer, as having afforded him valuable assistance, and as likely to afford important aid to those who desire further information on their respective subjects. In regard to a large proportion of them he may remark, that no previous work on Human Physiology has included their results.

Nervous System.

Dr. Marshall Hall on the Diseases of the Nervous System, 1841; Valentin, de Functionibus Nervorum, Berne, 1839; Leuret, sur l'Anatomie Comparée du Systeme Nerveux, 1839; Dr. John Reid, on the Functions of the Eighth Pair of Nerves, in the Edinburgh Medical and Surgical Journal, Vols. XLIX. and LI.; Dr. W. Budd, on the Pathology of the Spinal Cord, in the Medico-Chirurgical Transactions, Vol. XXII.

Muscular Fibre.

Mr. Bowman on the Structure of the Fibre of Voluntary Muscle, Philosophical Transactions, 1840; Dr. J. Reid on Muscular Contactility, in Transactions of British Association, Vol. IV., and in Edinburgh Monthly Journal of Medical Science, May, 1841.

Organic Functions.

Dr. Prout, on Stomach and Urinary Diseases, 1840; Gerber's General Anatomy, with Additions by Mr. Gulliver, 1841; Dr. Macartney on Inflammation, 1838; Dr. Barry on the Blood-corpuscles, Philosophical Transactions, 1840 and 1841; Sir A. Cooper on the Breast, 1840; Owen's Odontography, Part I. 1840; Nasmyth's Three Memoirs, 1841; Goodsir on the Development of the Teeth, Edinb.

Med. and Surg. Journ. Vol. LI.; Graham's Elements of Chemistry, 1841.

Reproduction.

Dr. Barry's Researches on Embryology, Phil. Trans. 1837-40; Dr. Montgomery on the signs of Pregnancy, 1837; Quetelet, sur l'Homme, ou Essai de Physique Sociale, 1835.

The Author has derived much of his information on the Voice and the Organs of the Senses, from the "Elements" of Prof. Müller; in which these subjects are treated with such minuteness, that the portion of his work devoted to them has almost the character of a Monograph, whilst it is thus rendered unfit for the purposes of the ordinary student. He may allude in a similar manner to the Physiology of Prof. Wagner, as one of the chief sources of his information on Reproduction and Development; and to it he would refer those who desire to obtain more information on that subject, than he deemed it consistent with the practical objects of this Treatise to give.

In regard to this, as to his former Treatise, the Author believes that he may claim a somewhat higher character than that of the mere Compiler; and that even the well-read Physiologist will find in it many facts and deductions, which have not been previously brought before him in the same form. He may especially direct attention to the views he has expressed in regard to the relations of Instinct and Intelligence, and to the location of the former in the Ganglia of Special Sensation; and to those which relate to the respective functions of Fibrin, Albumen, and Gelatin, as well as to other subjects treated of in the chapter on Nutrition.

In apportioning the amount of space to be devoted to each division of the subject, the Author has had in view its practical relations much more than its merely scientific interest; and he has on this account bestowed a much larger share on the Organs of Animal life than some may think just, when compared with the narrow limits within which other important topics are discussed. But he has endeavoured to keep always in view, that he is writing for the guidance of the Student who is to become a practitioner, rather than for him who makes the pursuit of Science his professed object; and that much that is of the highest interest to the latter, is comparatively valueless to the former. Hence many topics of great scientific interest are entirely passed over; and it is hoped that such omissions will not be accounted as faults in the estimation of those, who dread lest the attention of the Student should be too much drawn off by the seducing novelties of Science, from his less attractive, but more important objects.

For a large part of his illustrations, the Author is indebted to the valuable and beautiful Icones Physiologicæ of Prof. Wagner. The sources of all are indicated.

In conclusion, the Author would repeat what he has already had occasion to state;—that in a work involving many details, it is not to be expected that no error should have crept in; but that he has endeavoured to secure correctness, by relying only upon such authorities as appeared to him competent, and by comparing their statements with such general principles as he considers well established. For the truth of those principles, he holds himself responsible; for the correctness of the details he must appeal to those from whom they are derived, and to whom he has generally referred. He hopes that he will not be found unwilling to modify either, when they have been proved to be erroneous; nor indisposed to profit by criticism, when administered in a friendly spirit.

PREFACE OF THE AMERICAN EDITOR.

The peculiar character of Dr. Carpenter's "Human Physiology," particularly adapts it to the wants of the medical student. The close connection between Physiology and the practical branches of medicine, has been throughout the work carefully borne in mind, and their intimate relations pointed out. The present Treatise will be found to be a concise, yet comprehensive exposition of the actual condition of physiological science, conceived and executed in a clear and philosophical spirit. With much that is profound and original, the Author has presented all the received or probable facts of the Science of Life, in a well digested and lucid manner, deducing from them legitimate inferences, and carefully abstaining from the discussion of controverted questions, and never hazarding any startling hypothesis.

In the present edition much new matter has been introduced, with a number of additional illustrations. The able report of the Author on the Physiology of Cells, published in the British and Foreign Medical Review for January, 1843, has, at his request, been incorporated. The daily progress of physiology required that the Editor should make some additions, with an occasional revision and modification of the text. This last has been done in strict accordance with the wishes and views of the Author. The Editor has been largely indebted to the excellent work of Dr. Todd and Mr. Bowman, recently published;* as well as to the admirable Report on Microscopic Anatomy, by Mr. Paget.†

The new matter of the Author is distinguished thus [C.]; that by the Editor thus {M. C.}.

The Editor has abstained from noticing the new views on many subjects connected with physiology, lately promulgated by Professor Liebig. Regarding, as he does, the labours of that eminent chemist so far as rather suggestive than positive, he did not deem it advisable to introduce into a work of this kind views, which, however ingenious, are, at best, of very questionable correctness.

230 Spruce Street, August 10th, 1843.

* Physiological Anatomy and Physiology of Man. London, 1843.

† Report on the chief results obtained by the use of the Microscope in the study of Human Anatomy and Physiology. London, 1842.

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EXPLANATION OF FRONTISPIECE.

The first 16 Figures in this Plate are from Dr. Barry's Embryological Researches in the Philosophical Transactions for 1837, 1839, and 1840. The succeeding five are copies of the figures of Wagner.

FIG.

1. A very early stage of the formation of the Ovum; vesicles, the largest of which measures only 1-1125th of an inch, are seen in the midst of dark granules or globules (§ 470).
2. A stage somewhat more advanced; the vesicles are surrounded by envelopes of smaller vesicles, amongst which the granules are still seen (§ 740).
3. A still later stage; a central vesicle *a* is seen, with a spot *b* upon its walls, and surrounded with numerous granules; this has now evidently become the germinal vesicle (§ 740).
4. Ovisacs from Human ovum, 1-280th of an inch, and upwards, in diameter; the largest exhibits the germinal vesicle *a* very distinctly (§ 740).
5. Ovisac from Cat, showing its contents when near maturity; *a*, ovisac; *b*, its contained granules; *c*, zona pellucida; *d*, granules of the yelk; *e*, germinal vesicle; *f*, germinal spot; magnified 440 diameters (§ 739).
6. Ovum of Rabbit at the periphery of the Graafian vesicle, with part of the membrana granulosa removed; *g*, *g*, membrana granulosa; *o v*, ovulum; *r*, retinacula (§§ 740, 744).
7. Ovum with its tunica granulosa and retinacula removed from the Graafian vesicle; *a*, germinal vesicle; *b*, germinal spot; *c*, zona pellucida; *d*, globules of the yelk; *r*, *r*, retinacula; *t g*, tunica granulosa (§ 740).
8. Graafian vesicle discharging its ovum, *o v*, to which the tunica granulosa, *t g*, and retinacula, *r*, *r*, remain attached (§ 744).
9. Ovarium Ovum in preparation for fecundation: *a*, germinal spot, beginning to resolve itself into cells at its margin; *b*, germinal vesicle; *c*, elliptical cells in the place of the yelk; *d*, zona pellucida. 100 Diameters (§ 745).
10. Ovum nearly ready for fecundation: *a*, germinal spot more fully developed into cells, of which concentric layers occupy the germinal vesicle *b*; *c*, elliptical discs or cells; *d*, zona pellucida; *e*, substance of the yelk (§ 745).
11. Fecundated ovum of nine hours; the germinal vesicle, having returned to the centre of the ovum, is concealed by the large elliptical discs, which fill the cavity of the zona pellucida (§§ 745, 746).
12. Plan of one of these discs or cells: its nucleus, *a*, has developed itself into concentric rings of cells; and in the most fully-developed of these, the nucleus, *b*, is seen to be commencing the same kind of evolution. In the centre of the original nucleus, a pellucid spot, the nucleolus of Schwann and Schleiden, is observed (§ 745).
13. Ovum from the uterus, measuring about 1-68th of an inch in diameter: *a*, pair of cells now occupying the greater part of the germinal vesicle *b*; *c*, zona pellucida; *d*, chorion, a new envelope, separated from the last by the fluid it has absorbed (§ 746).
14. Ovum, of which the essential part, *a*, the pair of cells occupying the germinal vesicle, has advanced further than in the last case; the other contents of the germinal vesicle have undergone liquefaction. The chorion is here incipient; and the remains of the cells of which it is composed are seen at *cho* (§ 747).
15. More advanced ovum; the cavity of the germinal vesicle filled with cells, *a*, that have originated in the two represented in the last figure; these cells have nuclei, *b*, which are undergoing a corresponding process of evolution into secondary cells; *c* and *d* as in Fig. 13 (§ 758).

FIG.

16. Ovum in a state rather more advanced; *a*, central cell of the germinal mass, now come to the surface, and showing a nucleus *b* with a pellucid centre, from which most of the embryonic structures are developed; *c*, cavity in the germinal mass, caused by the approach of its peripheral cells to the enclosing membrane, *d* (§ 758).
17. Formation of the membrana decidua; *a*, *a*, *a*, villi of the mucous membrane of the uterus; *b*, substance secreted between and upon these; *c*, uterine vessels prolonged into the decidua and forming loops.
18. Human Spermatozoa; *a*, seminal granules (§ 735).
19. Cyst of evolution (§ 735).
20. Capsular bundle of spermatozoa, just previous to their separation (§ 735).
21. Globules from the chyle; *a*, ordinary globules; *b*, a globule (cytoblast?) surrounding itself with an envelope (a forming cell?); *c*, minute molecules of chyle; *d*, chyle or lymph globule (?) from the blood (§ 563).
22. Particles of blood undergoing multiplication; *a*, *b*, *c*, *d*, *e*, successive stages. After Barry (§ 576).
23. Extremity of one of the tufts of fœtal vessels forming the placenta; this includes (like a branchial tuft) an artery and vein. After Reid (§ 749).
24. Plan of the structure of the placenta, according to Dr. J. Reid's view of it; *a*, *a*, portion of substance of uterus; *b*, *b*, *b*, *b*, section of uterine sinuses, some of them opening on the inner surface into the cavity of the placenta; *c*, curling artery of uterus; *d*, *d*, ramifications of fœtal vessels, some of them sending down prolonged tufts which dip into the uterine sinuses (§ 749).

LIST OF WOODCUT ILLUSTRATIONS.

INTRODUCTION.

GENERAL VIEW OF THE CONNECTION OF PHYSIOLOGY WITH OTHER BRANCHES OF MEDICINE.

1. The object of the Science of Physiology is to bring together, in a systematic form, the phenomena which normally present themselves during the existence of living beings; and to classify and compare these, in such a manner as to deduce from them the general laws or principles by which they are regulated. In order to attain a correct knowledge of the latter, a very extensive comparison of this kind is requisite. Principles, which might seem of paramount importance in regard to one group of living beings, are often found, on a more general review, to be quite subordinate. For example, the predominance of the Nervous System, in the higher classes of animals, and its evidently close connection with many of the functions of life, has led several Physiologists to the opinion, that its influence is essential to the performance of the functions of Nutrition, Secretion, &c.: but, on turning our attention to the vegetable kingdom, in which nothing analogous to a nervous system can be proved to exist, we find these functions going on with even greater activity than in animals. It is clear, therefore, that they *may* be performed without it; and on a closer examination of the phenomena presented by animals, it is seen that they may be explained equally well, or even better, on the principle that the nervous system has a powerful influence on these actions, than that it affords a condition essential to them. This is only one out of many instances which it would be easy to adduce, in proof of the necessity of bringing together all the phenomena of the same kind, in whatever class of living beings they may be presented, before we erect any general principles in Physiology.

2. The object of the present work, however, is not to follow out such an investigation, but to show the detailed application of the principles of which physiological science may now be said to consist, to the phenomena exhibited by the human being, during what may be called his *normal life*. Every one knows the difficulty of defining the two conditions—*health* and *disease*. The former may be said to be that state in which the various actions of life are *normally* or regularly performed; and the latter to result from a disturbance or irregularity in these actions, constituting an *abnormal* state. But this is only substituting one term for another;—the difficulty remains the same. Many variations occur, within the limits of what must be called in some persons the normal state, which in others must be regarded as abnormal actions. Thus in most adults the pulse averages about 70; but it is easily raised by exercise to 90, without any injurious consequences; and such must be regarded as a normal or physiological state. But we occasionally meet with instances in which the usual pulse is not

quicker than 40; and for this to rise to 90 might indicate a very alarming state of the system; since there are individuals in whom such a pulse would be equivalent to one of 140 in a person whose circulation was in health of the average rapidity. Thus an abnormal state in any individual can frequently be ascertained only by comparison with his normal condition. This is a difficulty from which we can never hope to make a complete escape; for it is the peculiar character of living beings to exhibit such variations in their phenomena, resulting from the number of concurrent causes which are involved in the production of these; a slight alteration in any one of which, will most seriously affect the general result. Upon the distinction between normal and abnormal life, however, is founded that of the two sciences Physiology and Pathology. These are very closely related to each other; and neither can be pursued with the prospect of complete success, except in connection with the other.

3. The relation between the sciences of Physiology and Pathology on the one hand, and the various departments of the *Ars Medendi* on the other, may be shown within a brief compass; and it is perhaps desirable to point them out here, in order to place the importance of these sciences in its proper light. Science must strictly be said to consist of general principles, embodying the phenomena which present themselves to the observer, in any particular department of observation; and a science is perfect, in so far as its collection of facts is reducible to these general laws, the ascertainment of which enables us to extend our knowledge of similar facts. An art is, properly speaking, the application of a science to practical purposes, consisting of a set of rules deduced from its principles; and its perfection will be exactly proportional to that of the science upon which it rests. The most perfect of all sciences is Astronomy; all its leading phenomena may be reduced to one general principle; and phenomena, previously unobserved, have been predicted as the necessary results of that principle. The art of Navigation is a collection of rules framed by those who are profoundly conversant with the principles of the science, but capable of being employed by those, whose knowledge extends no further than to the mode of applying them. When, however, the science has not this degree of perfection, the art has not this independent character. In Chemistry, for example, many principles of high generality have been attained; and yet unknown phenomena cannot be predicted from them with certainty (in a great variety of cases at least), owing to the number of other conditions by which they may be affected. Hence no art founded upon this science can be supplied with any other than very limited rules. In the case of Dyeing, for example, great improvement has been effected by chemical knowledge; but the greater part of its rules are *empirical*, that is to say, founded on a limited induction, not comprehended in more general principles, and therefore quite uncertain in their results. Thus, if a new animal or vegetable dye were discovered, the modes of fixing and discharging it, and of varying its shades of colour, would have to be determined by experiment, before it could be brought into advantageous employment. We can nevertheless imagine, and (from the recent great advance in Organic Chemistry) in some degree anticipate, the period, when chemical science shall be so far advanced, that a simple analysis of the material (supplying data corresponding to the solar or lunar observations of the navigator) may enable the manufacturer, by a reference to his code of rules, to avail himself to the fullest extent of its capabilities, without being himself aware of the principles upon which those rules are founded.

4. An art, then, will be *scientific* or *empirical* (that is, its rules will be

based upon general principles, or upon induction from a limited experience,) in proportion to the comprehensiveness of the laws that have been attained in the science on which it rests. This distinction, however, has nothing to do with the certainty or uncertainty of its application in particular instances. An art may be entirely empirical, and yet be perfect so far as it goes; but no unknown cases are provided for, no contingencies foreseen. It is in its adaptation to these, that the triumph of a scientific over an empirical art manifests itself; and in proportion as, from the nature of the subjects embraced by it, a greater or less variety of novel cases presents itself, in that proportion is its superiority more evident. It was well observed by Lord Bacon, that "it is the office and excellence of all sciences to shorten the long turnings and windings of experience." The deficiency of higher or more comprehensive laws should not prevent us from making cautious use of those we already possess; and, where the demands of mankind require that an art should be practised even in its imperfect condition, we must be content with such means of satisfying them, as lie within our reach. Contentment, however, by no means involves a tacit acquiescence in the infirmities of our condition; and the man of noble and elevated mind will not only aim at the perfection of his science, from that abstract love of knowledge, which is, as Sir H. Davy has beautifully remarked, "in its ultimate and perfect development, the love of infinite wisdom and unbounded power, or the love of God," but may also safely cherish the belief, that every contribution which he makes to general laws will ultimately have its practical bearing on the condition of humanity.

5. In no department of inquiry is it more necessary to keep these principles in view, than in that which relates to the phenomena of Vitality. The changes which characterize living beings, and which in their totality constitute the Life of these, are as capable as phenomena of any other kind, of being referred to general laws expressive of their uniform conditions. But there are many causes which render the attainment of these laws so difficult, that at present we cannot assign to Biology (a term which may be advantageously employed for the science of Vital Action, including Physiology and Pathology) a high rank amongst the sciences. Hence the rules of any arts which are founded upon it, can be only in part regarded as possessing that certainty, which it is desirable they should have. Some there are, which are derived from laws of such high generality, that we cannot imagine any cause which can interfere with their application. For example, it is one of these facts of universal application, that a large mixture of carbonic acid in the medium to which the circulating fluid is exposed for aëration, is prejudicial to life; and an obvious rule thence follows. But it is not a fact of equal universality, that a dose of a purgative medicine will induce increased action of the bowels; for there may be many conditions of the system in which this shall not occur. The physician, in directing the ventilation of a room, would be guided by a high scientific principle; whilst in administering a medicine, he is working upon an induction derived from a comparatively limited experience.

6. The art which most directly springs out of the science of Physiology, is that of Hygiène, which may be defined as a system of rules for the preservation of the body in health, deduced from the principles by which its actions are governed. Were the science of Physiology perfect, the art would require little skill for its practice; this, however, is far from being the case. Its rules are at present founded, in great part, upon too limited an induction to deserve the title of universal; and their operation is frequently interfered with by a number of causes, of whose mode of action we

are almost entirely ignorant. Still much has been done, by calling public attention to those of which the general importance is acknowledged, in preserving the body in health by removing the causes of disease; as the increased value of human life, shown by statistical returns, abundantly testifies. And the physiologist can readily point out many more, which have not yet received the attention that their importance deserves. The term Hygiène is sometimes used to include the art of restoring as well as preserving health, by the use of means not strictly to be regarded as medical, *e. g.* the regulation of diet, temperature, &c.; but this employment of it is not strictly correct, such treatment being properly a part of Therapeutics,—an art which stands in the same relation to Hygiène, that Pathology bears to Physiology. In proportion as the science of Physiology is perfected, will the simplicity and certainty of its practical applications increase; and though we may not anticipate a return of patriarchal longevity, yet the experience of the last century has amply shown, that every general increase of attention to its simple and universally acknowledged truths, is attended with a prolongation of life, and that not less important object—its emancipation from disease. Hence the establishment of the rules of Hygiène may be considered as the most direct practical benefit afforded by the pursuit of physiological science.

7. In the assistance which it affords, however, in the establishment of the principles of Pathology, the importance of Physiology is by no means inferior; and it is surprising how much the relation of the two has been neglected. That the knowledge of the normal actions of a living system is essential to success, in the investigation of the causes and mode of cure of its irregularities,—seems almost a self-evident proposition. We should all think it absurd for a person to attempt to repair a watch or a steam-engine that might be acting wrongly, who is unacquainted with the uses of the several parts of its structure, both singly and in combination with each other. He might have such an acquaintance with their form and mechanical arrangement, as might enable him to delineate them, or even to construct the counterpart of the whole machine, without being able to put it into successful operation. Just so it is with the anatomist, who regards the *mere* acquaintance with the *structure* of the human body as a sufficient guide in the treatment of disease. But this is really of little assistance in any thing but surgical operations; that which we require to know, for the rectification of morbid phenomena, being the normal history of those phenomena, and the conditions on which they are dependent. The neglect of physiological science as an adjunct to the *ars medendi*, may probably be in part attributed to the facility with which striking curative effects may often be produced, by the application of empirical rules only. Thus a person usually healthy, who is suffering from headache, feverishness, and constipation,—the effects of an overloaded alimentary canal,—may be pretty certainly relieved by a brisk purge; or a stout child, who is suffering from cough, tightness of the chest, and heat and dryness of skin, resulting from recent exposure to cold and damp, by a strong dose of an antimonial. These are results with which every tyro is well acquainted; they are based upon ordinary experience, and, if applied without further consideration of their rationale, are strictly empirical. The case might be compared to that, in which a person unacquainted with the construction or principles of action of a watch or a steam-engine, alters its rate of movement, by shifting a lever or opening a cock. But, though usually successful, exceptional cases will occur, in which unexpected results will follow; and the merely empirical practitioner is baffled and confounded. For these, something more is requisite; and no treatment can be successful, otherwise than

by an accidental coincidence, in which the causes of the derangement are not carefully inquired into, and their operation understood. And how can their operation, in producing a disturbance of the system, be comprehended, when its regular actions are not even known,—far less, their principles ascertained?

8. The study of Physiology, being the inquiry into the phenomena of normal life and the conditions of those phenomena, requires a knowledge of the two sets of causes which must be concerned in them,—the organized structure or mechanism, possessed of certain properties,—and the agents or stimuli, by whose operation on this mechanism its properties are made to develope themselves in the production of phenomena. These require to be separately considered; just in the same manner as when, in examining the action of a steam-engine, we inquire into its mechanical structure, and the effects upon it of the agencies by which it is put in operation. Now in the study of Pathology, or the science of diseased action, we have to attend, in the same manner, to two sets of conditions. On the one hand, we have to make ourselves acquainted with the characters of all the external agents, which can produce a deleterious effect upon the living body, whether their operation be mechanical, chemical, or more directly vital; as well as with the results of the suspension, partial or complete, of the conditions by which its healthy action is maintained. On the other side, we have to investigate the changes of structure which manifest themselves in the body itself, the causes by which these are produced, and the new results which they will themselves occasion. Now one of the chief difficulties in the pursuit of pathological science results from this,—that we are at present so imperfectly acquainted with the conditions required for normal action, that we cannot ascertain what those are in which the derangement primarily consists. Hence we are in constant danger of mistaking the more evident changes, which are often but secondary results of the morbid action, for the real source of the disease. For example, we are not yet sufficiently acquainted with the conditions necessary for the transmission of nervous influence, to be able to state when those conditions are interfered with; hence a great extent of morbid alteration not unfrequently presents itself, in the parts which we know to be concerned in this operation, without such symptoms as we should expect to correspond with it; and, on the other hand, we frequently observe during life most decided deviations from the ordinary sequence of nervous phenomena, which we cannot attribute to any change of structure that we can discover after death. Here, then, is a case in which Pathology must necessarily be imperfect, until Physiology has greatly advanced; and numbers of similar instances might be pointed out. Again, it would be easy to show the direct benefit which the physician has derived from the physiologist, by reference to the same class of phenomena; but for this we may refer to the subsequent part of this treatise, in which the chief practical applications of late discoveries as to the functions of the Nervous System, will be set forth. It will be scarcely questioned, then, that the science of Pathology has so direct and immediate a dependence upon that of Physiology, that the former cannot be pursued with a fair prospect of success, without a knowledge both of the principles and of the chief phenomena of the latter.

9. Another illustration may be useful. Few pathologists regard any morbid process as better understood than that of Inflammation; and yet scarcely any two are agreed as to its real nature. By some its essential condition is stated to be a contraction or a dilatation of the capillary vessels; and this alteration is supposed by one to result from an exalted—and by

another from a diminished—degree of vitality in their walls. Others, again, regarding inflammation as an affection of the sensory rather than of the organic functions, have imagined its seat to be in the nervous system. Now it may be stated with tolerable confidence, that no theoretical view of the nature of inflammation has exerted any beneficial influence on its treatment; and that all the rules of practice to which we trust for the cure, are founded on experience alone. It is therefore evident, that there must be something very faulty in the mode of cultivation, since the fruits yielded by a domain so fertile of phenomena are thus useless; and the physiologist has not much difficulty in pointing out several sources of error, that have resulted from the insufficient acquaintance possessed by most pathologists, with those normal actions of which inflammation is a disturbed form. Thus, he can show that inflammation is not primarily a disorder of the function of circulation, but rather of nutrition, the vascular apparatus being only secondarily affected; so that no observations on the state of the vessels, and on the movement of the blood through them, give us any real information as to the nature of the morbid action. Further, he is aware that no inferences can be valid, that are founded on experiments made on the cold-blooded vertebrata, since in them the true inflammatory state can with difficulty be induced; and also, that the nervous system cannot be an element in the primary phenomena of inflammation, since these are manifested by beings that do not possess it. It will hereafter be pointed out, that, by attention to the principles of Physiology, our knowledge of the real character of this and of many other morbid processes, is now being rapidly increased; and that it is at the same time acquiring a degree of definiteness, which cannot but lead to important improvements in practice.

10. As Hygiène, or the art of preserving health, arises out of the science of Physiology, so does the Therapeutic art depend upon the science of Pathology; or, to use language rendered venerable by its antiquity, the *ars medendi*, to be perfect, must be guided by the *ratio medendi*. The term Therapeutics, however, is sometimes used to denote that division of the science of Pathology, which concerns the principles of the application of curative agents to the treatment of disease. There is no real ground, however, for distinguishing this as any other than a section of Pathology; or for considering the practical use of these principles as any thing but an art. As life, in the healthy condition, is known to be maintained by the operation of external agents upon organized tissues endowed with vital properties,—so is it found that, in diseased states of the system, such a change takes place in the character of these actions, as adapts them to its altered circumstances; thus, in a febrile condition, when any increase of stimulus would be injurious, there is no longer an appetite for food. Moreover, it is found that by the regulation of the natural actions, or the substitution of new ones, the diseased condition may frequently be controlled, and the normal action restored. Hence the inquiry into the curative influence of external agents upon the phenomena of disease, is as much a part of the science of Pathology, as the study of the influence of the ordinary vital stimuli, in producing the normal actions of the system, is a division (as it is universally allowed to be) of the science of Physiology. If this inquiry had terminated in the discovery of general principles, all difficulty would be removed from the therapeutic art, as soon as the perplexities of diagnosis had been overcome; and, in proportion as such are approached, and our knowledge of the essential nature of diseased actions is extended, will be the facility and the success of our curative treatment.

11. In the mean time the practitioner must be content to follow a middle

course. His aim must be to avoid, on the one hand, confiding too exclusively in general principles, however stable and comprehensive he may imagine them to be; until he is satisfied that he knows not only the principle itself, but the subordinate laws which regulate or modify its application to individual cases. Long after the highest laws of motion had been established by Newton, no astronomer could, on the faith of them, have predicted the situation of a planet with more than an approximation to certainty; the law of attraction had to be applied in numberless modes not contemplated by its discoverer, before perfect accuracy could be attained. There is great danger, then, in the present state of the science of Pathology, in trusting to principles which we may consider unassailable, as our sole guides in the practice of our art; and hence it is not always the *scientific* practitioner, as he is emphatically termed, who is the most successful in his treatment. On the other hand, to apply a particular mode of treatment to a particular set of symptoms, without inquiring into the cause of those symptoms, merely on account of its having been successful in some case that *appeared* analogous, is a mode of practice completely empirical. Yet such a plan is constantly being pursued. But as soon as we begin to inquire into the cause of the morbid action, and seek to remove or counteract this by the application of remedial means which experience has shown to be effectual for such an object, we are really acting to a certain extent on scientific principles. The recorded experience of ages, in its condensed form, must of necessity assume the appearance of general rules of practice; and it is in the application of these rules to individual cases, and in the distinction of those phenomena whose causes are subservient to them, from those which are beyond their pale and which require a mode of treatment altogether different, that the sagacity of the practitioner most displays itself. The *rational empiricism* which prevails in this country at the present day, is a mode of practice that may be regarded as best combining the advantages of scientific knowledge and of recorded experience. The value of *facts* as the only sure basis of general principles is duly appreciated; and yet there is no indisposition to make trial of such *principles* when announced, and to abide by them so far as they appear practically available. This is the only method in which the young practitioner can hope to succeed. The increased attention at present paid to diagnosis, will frequently enable him to determine the real nature of the malady, with much more precision than can be done by a man of age and experience, who has not kept pace with the progress of medical science; whilst the latter will have decidedly the advantage in the application of therapeutic means, especially in those obscure cases which require the tact, that can only be acquired by long and attentive observation.

12. The *numerical method*, which is at present much valued by many as a guide in the Study and Practice of Medicine, is simply a statistical arrangement of the phenomena presented by various diseases, with a view of determining the frequency of their occurrence, their connections with each other, and the influence of various modes of treatment upon them. Its advantages in substituting an accurate and definite record of facts, for the vague statements which we so frequently meet with, are unquestionable. Yet we must be careful not to attach too much importance to the results afforded by it. They have a tendency to lead to the substitution of empirical rules for scientific principles; and if too exclusively followed, therefore, will tend to the retardation of Pathology. If the practitioner is led to reason thus on every particular instance,—"In nine-tenths of the cases exhibiting these symptoms, such-and-such a treatment is successful; therefore I shall adopt this treatment in the present one,"—he is acting

on a most grossly empirical system. A general law admits of no exceptions; and if such appear to present themselves, they must be due to some cause interfering with its operation. His object ought to be rather, therefore, to ascertain what plan of treatment is *constantly* successful in each form of disease; in other words, to determine that *invariable* sequence of cause and effect, on which alone general principles or laws can be erected; and in order to do this, he must carefully analyze the unsuccessful cases, and ascertain in what their conditions differed from the rest, so as to be able to determine positively to which head he is to refer the case before him, and to be guided in his treatment accordingly. In this manner he will advance the Science; whilst in the other he is reducing the Art to its lowest condition.*

* For a lucid analysis of the value of the numerical method, Dr. Symond's Retrospective Address (at the Liverpool Meeting of the Provincial Medical Association) may be advantageously consulted.

CHAPTER I.

ON THE PLACE OF MAN IN THE SCALE OF BEING.

Distinction between Animals and Plants.

13. In entering upon the survey of the Animal Kingdom in general, which it is desirable to take, before we consider in detail any particular member of it, the question naturally arises,—how is the Animal distinguished from the Vegetable? There is no difficulty in replying to this, if we keep in view merely the higher tribes of each division; no one, for example, would be in any danger of confounding a Whale with a Palm, or an Elephant with an Oak. It is when we descend to the opposite extremity of the scale, that we encounter the greatest difficulty; from the circumstance, that the distinguishing characters of each kingdom disappear, one after another, until we are reduced to those which seem common to both. So completely is this the case, that there are many tribes which cannot, in the present state of our knowledge, be referred with certainty to either one division or the other. We are accustomed to think of Animals as beings, which not only grow and reproduce themselves, but also possess the power of *spontaneously* moving from place to place, and are *conscious* of impressions made upon them: and we usually regard Plants as beings which are entirely destitute of sensibility and of the power of spontaneous motion,—going through all their processes of growth, reproduction, and decay, alike unconscious of pleasure and of pain, and devoid of all power of voluntarily changing their condition. Such a definition is probably the most correct that we can employ; but great difficulties lie in the way of its application. There are many tribes, which possess a general structure more allied to that of beings known to be Animals, than to that of any Plants; and which yet present no decided indications either of sensibility or of voluntary power. Such is the *Sponge*, the fabric of which closely corresponds with that of many Alcyonian Polypes, whose animality is undoubted; and yet neither observation nor experiment have ever succeeded in proving, that the sponge feels or spontaneously moves. Yet there are no known vegetables to which it presents any near resemblance. On the other hand, there are many vegetables which perform evident movements, which, at first sight, appear to be spontaneous, indicating sensibility on the part of the being that performs them. Such movements, however, can in some instances (as in that of the Sensitive-Plant or Venus's Fly-trap) be referred to a sort of mechanism, the action of which does not involve sensibility, and which may be compared with the many movements (such as that of the heart) that are constantly taking place in the bodies of the highest animals, without their consciousness; and in other cases (as in the *Oscillatoriæ*) they are so *rhythmical*, as to impress the observer with the idea, that they are rather the result of some physical, than of any mental influence. In this respect they correspond with the motions of the con-

stantly vibrating *cilia*, which cover the surface of the mucous membranes of animals.

14. However difficult it may be for us, owing to our imperfect knowledge, to draw the line in individual cases, it cannot be doubted that a boundary does exist; and in general a very simple mark will suffice to establish the distinction. This mark is the presence or absence of a stomach or internal cavity for the reception of food. The possession of a stomach cannot be regarded, however, as in itself an essential distinction between the two kingdoms (as some have represented it); for its presence is merely a *result*, so to speak, of the nature of the food of animals, and of the mode in which it is obtained. Vegetables are dependent for their support, upon those materials only which they obtain from the surrounding elements; carbonic acid, water, and ammonia, duly supplied to them, with a small quantity of certain mineral ingredients, afford all the conditions they require for the production of the most massive fabrics, and the greatest variety of secretions. But these same elements, if supplied to animals, could not be converted by them into the materials of organized structures; for *they* can only employ as food substances which have been already organized, and are consequently dependent, either directly or indirectly, upon the Vegetable kingdom, for their means of support. Now they cannot incorporate these alimentary substances into their own tissues, until they have been reduced to the fluid form; hence they need the means of performing this reduction, which are supplied by the stomach. Again, they cannot be always in immediate relation with their food; they have to go in search of it, and need a store-room in which it may be deposited during the intervals; this purpose also is supplied by the stomach. It is evident, moreover, that the powers of voluntary locomotion and sensation, which animals enjoy, are connected with the peculiar nature of the food they require; for if they were fixed in the ground, like plants, they would not be able to obtain that which they require for their support. It is true that there are some which seem almost rooted to one spot; but these have the power of bringing their food within their reach, even though they cannot go in search of it. This is the case with many Polypes, which use their outspread tentacula for this purpose; and with the lower Mollusca, which can create currents by means of ciliary action.

15. A distinction might probably be erected between the Animal and Vegetable kingdoms, upon the mode in which the first development of the germ takes place. The seed of the plant, at the time of fertilization, principally consists of a store of nourishment prepared by the parent for the supply of the germ, which is introduced into the midst of it. The same may be said of the egg of the animal. In both instances, the first development of the germ is into a membranous expansion, which absorbs the alimentary materials with which it is in contact, and prepares them by assimilation for the nourishment of the embryonic structure, the most important parts (in the higher classes of animals, and in Phanerogamic plants, the only permanent parts) of which are in its centre. Now in plants, this membranous expansion (the single or double cotyledon) absorbs by its outer surface, which is applied to the albumen of the seed, and takes it more or less completely into its own substance. In animals, this expansion is developed in such a manner, that it surrounds the albumen, enclosing it in a sac, the *inner* surface only of which is concerned in absorption. This sac is, then, the temporary *stomach* of the embryonic structure; it becomes the permanent stomach of the Radiata; but in the higher classes only a portion of it is retained in the fabric of the adult,—the remainder being cast

off, like the cotyledon of Plants, as soon as it has performed its function. Thus, then, the first *nisus* of animal development is towards the formation of a stomach, for the internal reception and digestion of food; whilst the first processes of vegetable evolution tend to the production of a frond-like membrane, which, like the permanent frond of the lower classes of Plants, absorbs nourishment by its expanded surface only.

16. Some physiologists have asserted, that the nature of the respiratory process affords a ground of distinction between Animals and Plants,—oxygen being absorbed, and carbonic acid evolved, by the former,—and a converse change being effected in the surrounding air by the latter. It is not correct, however, to designate this converse change as a consequence of the respiratory process: for in plants, as in animals, there is a continual absorption of oxygen and evolution of carbonic acid, which constitute the function of respiration; but the effects of this change are masked (as it were) by those of the process of fixation of carbon from the atmosphere, which only takes place under the influence of sun-light, and which is much more analogous to the *digestion* of animals.

General subdivisions of the Animal Kingdom.

17. The Animal kingdom was formerly divided into two primary groups,—the *Vertebrated* and the *Invertebrated;* the former comprising those which are distinguished by the possession of a jointed spinal column consisting of a number of internal bones, termed vertebræ; and the latter including all those animals which are destitute of this support. It was pointed out by Cuvier, however, that, among the Invertebrata, there are three types of organization as distinct from each other as any of them are from the Vertebrata; and he accordingly distributed the whole under four primary divisions or sub-kingdoms: of these the VERTEBRATA rank highest; next, the ARTICULATA and the MOLLUSCA, which are both inferior in degree of organization to the Vertebrata, but are superior to the lowest group, the RADIATA, which contains those animals that border most closely, both in external aspect and in general character, upon the Vegetable kingdom. The members of these groups are readily separated from each other by the structure of their skeletons, or organs of support and protection; as well as by many other characters. In the Vertebrata, the skeleton consists of a number of internal jointed bones, which are clothed by the muscles that are attached to them and move them; these bones are traversed by blood-vessels and absorbents, and are to be regarded as in all respects analogous to the other living tissues of the body. In the Articulata, the soft parts are supported by a hard external envelope, which is of corresponding form on the two sides of the median line, and is divided into numerous pieces, jointed or articulated together by a membrane, in such a manner as still to allow of free motion; and the muscles, which are numerous and complex, are attached to the interior of these. In the Mollusca, the whole body is quite soft; and many species exist, in which it has no external protection: a large proportion of the group, however, have the power of exuding shelly matter from their surface, so as to form a protective habitation, within which the animal can withdraw its body, but which is by no means to be regarded as a part of it, and does not exhibit any definite type of structure. In the Radiata, all the parts are arranged in a circular manner, the mouth being in the centre; some of them are protected by firmly-jointed exterior skeletons like those of the Articulata; whilst others deposit calcareous matter in the centre of their soft fleshy structures, as if sketching out the internal skeleton of the Vertebrata.

The skeletons of the Invertebrata differ, however, from those of vertebrate animals, in this important character,—that they are not permeated by vessels, and are formed only by a superficial deposition. Hence they are termed extra-vascular; and it is an obvious result of an arrangement of this kind, that parts once formed are never changed, except by the ordinary processes of decay, and that they can only be extended by addition to their exterior; whilst in Vertebrata, the bones are subject to alterations of any kind, whether of removal or addition, throughout their entire substance. A more detailed account of the general structure of these sub-kingdoms will now be given, beginning with the lowest.

General characters of Radiata.

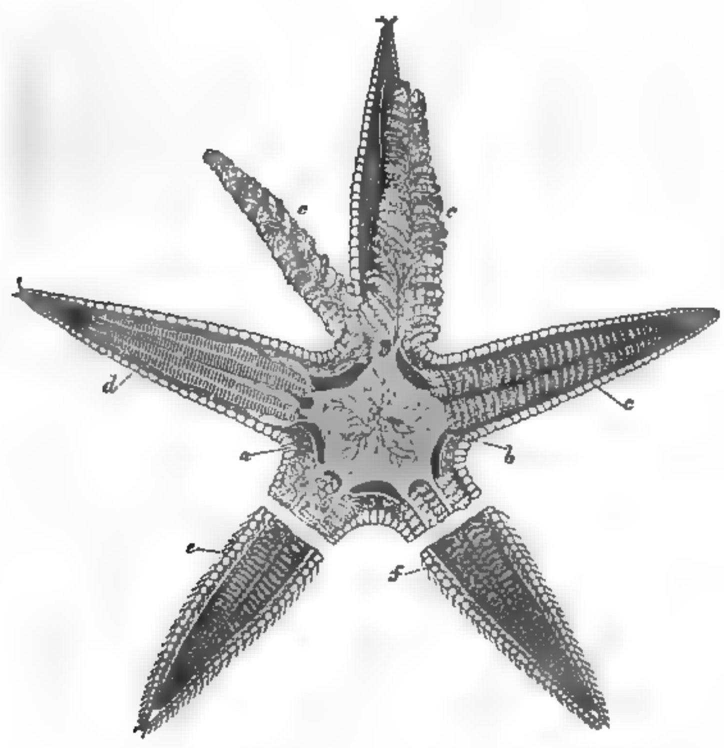
18. The Radiata possess many points of affinity with the Vegetable kingdom; and of these, the circular arrangement of their parts is one of the most evident. Many species of Sea-Anemone, for instance, present an appearance so much resembling that of various composite flowers, as to have been commonly termed Animal-flowers,—a designation to which they further seem entitled, from the small amount of sensibility they manifest, and the evident influence of light upon their opening and closing. But it is in the tendency to the production of compound fabrics,—each containing a number of individuals, which have the power of existing independently, but which are to a certain degree connected with one another,—that we recognise the greatest affinity in structure between this group and the Vegetable kingdom. Every tree is made up of a large number of buds, composed of leaves arranged round a common axis; each bud has the power of preserving its own life, and of reproducing the original structure, when removed from the parent stem, if placed in circumstances favourable to its growth; and yet all are connected, in the growing tree, by a system of vessels which form a communication between them. This is precisely the nature of those structures, which are formed by the animals of the class that may be regarded as the most characteristic of the group. Every mass of coral is the skeleton of a compound animal, consisting of a number of polypes, connected together by a soft flesh, in which vessels are channelled out; these polypes are capable of existing separately, since each one, when removed from the rest, can in time produce a massive compound fabric, like that of its parent; but they all contribute to the maintenance of the composite structure, so long as they are in connection with it. In some instances, the skeleton is stony, and is formed by the deposition of calcareous matter, either in the centre of each fleshy column, so as to form a solid stem, or on its exterior, so as to form a tube. In other cases, it is horny; and then it may be a flexible axis, or a delicate tube. Both the stony and horny corals often possess the form of plants or trees; and as their skeletons are often found with no obvious traces of the animals to which they belonged, they have been accounted vegetable growths. This idea receives confirmation from examination of their intimate structure; for they are composed of a tissue which bears more resemblance to the vesicular tissue of plants than to the cellular tissue of the higher animals. There is not the least doubt, however, as to the animal origin of the greatest part of these plant-like structures; and one group only, that of *Corallines*, remains a source of much perplexity to the naturalist.

19. The affinity, however, between the lowest Radiata and Plants, in regard to the vital phenomena they exhibit, is still more close than that manifested by their structure. Although in the higher groups, movements

may be constantly witnessed, which evidently indicate consciousness and voluntary power, this is far from being the case in the lower. There are many tribes, whose reception of food, growth, and reproduction, are not known to be accompanied by any phenomena, which distinctly indicate their animal character. The most violent lacerations produce no signs of sensibility; and the movements they occasionally exhibit have not so much of a spontaneous character, as those which are performed by many plants. This is the case, for example, with the *Sponge* tribe, and also with a number of microscopic species. So doubtful is the nature of these beings, that their animal or vegetable character is rather to be decided by their affinity with species known to belong to either kingdom, than in any other way.

20. It is very different, however, in regard to the higher Radiata. Even among the Zoophytes (as the plant-like animals just alluded to are commonly termed) there are some species which are unattached during the whole period of their lives, and have a power of voluntarily moving from place to place, such as is never possessed by plants. And in the highest class, the Echinodermata, including the Star-fish, Sea Urchin, &c., we meet with a considerable degree of complexity of structure, and a corresponding variety of actions. Still, except in those species which connect this group with others, the same character of radial or *circular* symmetry

Fig. 1.



Asterias aurantiaca, with the upper side of the hard envelope removed. *a*, central stomach. *b*, cæca upon its upper surface, probably answering to the liver; *c*, *c*, cæcal prolongations of stomach into rays; *c′*, *c′*, the same empty. *d*, the same opened; *e*, under surface, showing vesicles of feet; *f*, vesicles contracted, showing skeleton between them.

is maintained throughout; and in no animal is it more remarkable than in the common Star-fish. It is exhibited alike in its internal conformation and external aspect. The mouth, placed in the centre of the disk, leads to a stomach which occupies the greatest part of the cavity of the body; and this sends prolongations into the arms, which are exactly alike in form, and occupy a precisely similar position, in every one. Each arm is furnished, on its under side, with a curious apparatus for locomotion, consisting of a series of short elastic tubes, which are prolonged through apertures in the hard envelope, from a series of vesicles placed along the floor (as it may be termed) of the ray. The system of vessels for absorbing nutriment and conveying it through the system, is also disposed upon the same plan; and the same may be said of the nervous system, and of the only organs of special sensation which this animal appears to possess,—the rudimentary eyes, of which one is seen at the extremity of each ray.

21. Amongst other results of the repetition of similar organs, so remarkable in this group, is this,—that one or more of them may be removed without permanent injury to the whole structure, and may even develope themselves into an entire fabric. Thus in the Star-fish, instances are known of the loss of one, two, three, and even four rays, which have been gradually reproduced; the whole process appearing to be attended with little inconvenience to the animal. In some species of isolated Polypifera, such as the common Sea-Anemone, and Hydra (Fresh-water Polype), this power of reproduction is much greater. The Hydra may be cut into a large number of pieces (it is said, as many as 40), of which every one shall be capable of developing itself in time into a perfect polype. The Sea-Anemone, when divided either transversely or vertically, still lives; and each half produces the other, so as to re-form the perfect animal. This is another character, which shows the affinity of the Radiata to the Vegetable kingdom; and there is yet another, derived from their mode of reproduction. In many Polypifera, we observe a propagation by *buds*, in all respects conformable to that which plants effect, and quite different from the regular multiplication by distinct germs. This gemmiparous reproduction, as it is called, takes place, not only in the *compound* Polypifera, whose plant-like structures are extended by it, but also in some isolated species, such as the Hydra; from the body of which one or more young ones bud forth at the same time, and these buds may themselves put forth another generation, previously to their separation from their parent. This kind of reproduction is not seen anywhere else, in the whole Animal kingdom, except in a few of the lowest Mollusca and Articulata, which border most closely on the Radiata.

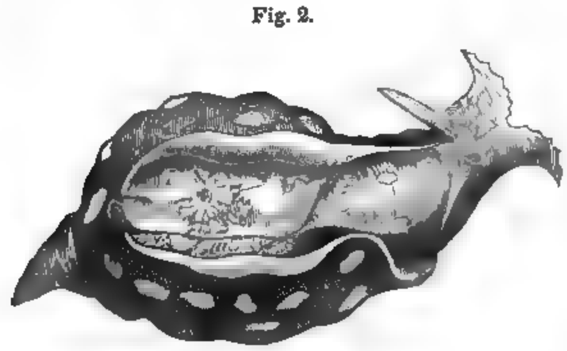
General characters of Mollusca.

22. The range of Animal forms comprehended in the sub-kingdom MOLLUSCA is so great, that it would be difficult to include them in any positive definition, which should be applicable to all. They present few traces of the circular disposition of organs around the mouth, which is characteristic of the radiated classes; and we seldom meet with any marked approach to the elongation of the body,—still seldomer with any indication of that division into segments,—which are the chief peculiarities of the Articulata. It is by the absence of these, and of any trace of the vertebrated structure, that the Mollusca are most readily defined. The variety of form which they present is less surprising, when it is considered, that the bulk of their bodies is almost entirely made up by organs of nutrition; and the organs of

sensation and locomotion which they possess are subservient to the supply of these. We find, in the lowest tribes of this group, living beings which are fixed to one spot during all but the earliest period of their lives; and which scarcely possess within themselves so much power of movement, as that enjoyed by the individual polypes in a compound polypidom; and yet these exhibit a complex and powerful digestive apparatus, a regular circulation of blood, and an active respiration. We never find, throughout the whole Animal kingdom, that the apparatus of organic life is arranged on any definite plan of its own; its conformation is adapted to the type which predominates in the structure of each group, and which is principally manifested in the disposition of the locomotive organs. Thus, the stomach of the Star-fish is circular, and sends a prolongation into each ray; whilst the digestive cavity of the Articulata is prolonged into a tube. In the Mollusca, there is no such definite type, the apparatus of nutrition having the predominance over that of locomotion; and the form of the body is, therefore, extremely variable. The relative places, even of the most important organs (such as the gills) are found to undergo complete changes, as we pass from one tribe to another; although their general structure is but little altered.

23. The lower Mollusca may be characterized as consisting merely of a bag of viscera; they have not even any prominence for the mouth, nor any organs of special sense, such as would distinguish a *head;* and they are entirely destitute of *symmetry,*—the *radiated* arrangement of parts seen in the lower tribes being absent, as well as the *bi-lateral* correspondence which is characteristic of the higher. In the more elevated Mollusca, however, which possess not merely sensitive tentacula, but eyes and even organs of smell and hearing, we find these disposed in a symmetrical manner; so that the head, which is the part concerned peculiarly in animal life, does present a bi-lateral equality of parts, even when the remainder of the body wants it. But in the more active among the higher classes, we find this bi-lateral symmetry extending to the exterior of the whole body, evidently bearing a pretty close relation to its degree of locomotive power. It is most evident and complete in the Cephalopoda (*Cuttle-fish* tribe); many of which are adapted to lead the life of Fishes, and resemble them in the general form of the body, and in the structure of many of the individual organs. It is also manifested in many of the shell-less Gasteropoda, such as the Slug, or the *Aplysia* (Sea-Hare), as will be seen by the accompanying representation of a species of the latter. But this symmetry does not

Fig. 2.



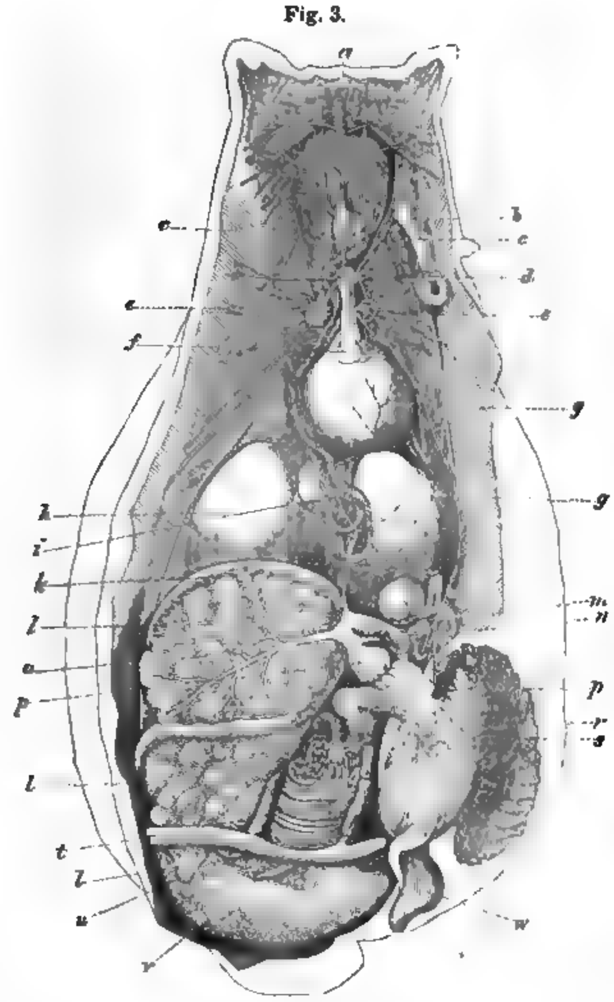
Aplysia depilans; *a*, branchiæ or gills.

extend to the arrangement of the *internal* organs, and appears to be only designed to adapt the body for more convenient locomotion.

24. As a group, however, the Mollusca are to be characterized rather by the *absence*, than by the possession, of any definite form; and there is a corresponding absence of any regular organs of support, by which such a form could be maintained. The name they have received designates them as *soft* animals; and this they are pre-eminently, as every one knows who has taken a slug between his fingers. The shell, where it exists, is to be regarded rather in the light of an appendage, designed for the mere protection of the body, and deriving its shape from the latter, than as a skeleton, giving attachment to muscles, and regulating the form of the whole structure. It is in no instance a fixed point for the muscles of locomotion; and it is only, indeed, where the body is uncovered by a shell, or a locomotive organ may be projected beyond it, that any active movements can be executed. This locomotive organ,—the *foot*, as it is commonly termed, —is nothing else than a fleshy mass formed by the increased development of the muscular portion of one part of the general envelope of the body, termed the *mantle*, in which the visceral mass is loosely included. The *mantle* is not essentially different from the skin of other animals; but it is usually thicker, possessing a considerable amount of muscular fibre interwoven with it, and its surface having frequently a glandular character. This general muscular envelope is the only locomotive organ possessed by a large proportion of the Mollusca; but its contractile properties are usually greatest at some particular spot, where it is thickened into a sort of disk, by the alternate contraction and extension of which the animal can slowly propel itself; this is well seen by causing a snail or slug to crawl over a piece of glass, so that the under surface of the disk may be seen whilst it is in operation. The general character of their locomotion, however, is well expressed by the term *sluggish;* and there are scarcely any among the typical Mollusca, whose activity is such as to demand for them any higher appellation.

25. The general development of their organs of nutrition, however, is much higher than is met with among the Articulata; and, in proportion to that of the organs of locomotion, it is much greater than will be elsewhere observed throughout the Animal kingdom. The justice of this statement will be made evident by a slight examination of the adjoined figure, in which the interior structure of the *Aplysia*, showing the general character of that of the group, is displayed. The only set of muscles which this animal possesses is that connected with the mouth, which it is able to push forwards or to draw back, and which possesses considerable powers of mastication, and is furnished with large salivary glands. The nervous centres (of which more will be said hereafter) are seen to be principally disposed around the œsophagus. The whole digestive apparatus is observed to be very complex and highly developed; the liver alone occupies a considerable part of the cavity. The heart has distinct muscular walls, and is divided into a separate auricle and ventricle; and a large respiratory organ is developed for the aeration of the blood. The position of the gills, which are external to the cavity, but which are concealed in part by a fold of the mantle, and in part by the rudimentary shell, is seen at *a*, Fig. 2. The generative apparatus, also, is highly developed. Yet with all this complex organization, the locomotive power of the animal is not much greater than that of the slug; no other means being provided for the purpose, than the contractility of the general envelope, which is greatest on the under side of the body.

Fig. 3.



Aplysia cut open, showing the viscera; *a*, upper part of œsophagus; *b*, penis; *c*, *c*, salivary glands; *d*, superior or cephalic ganglion, *e*, *e*, inferior, or subœsophageal ganglia, *f*, termination of œsophagus; *g*, *g*, first stomach, *h*, third stomach, *i*, second stomach, *k*, intestine, *l*, *l*, *l*, liver, *m*, posterior ganglion; *n*, aorta; *o*, hepatic artery *p*, ventricle of heart, *q*, auricle; *r*, *s*, branchiæ; *t*, testis, *u*, lower part of intestine; *v*, ovary; *w*, anus

26. The blood of the Mollusca is white, and the number of corpuscles in it is small. Their temperature is low, being seldom more than one or two degrees above that of the surrounding medium; but many of them are capable of being subjected to extreme variations of heat and cold, without their vitality being thereby destroyed. Their respiration is for the most part aquatic; and is performed by means of gills, over which a current of water is constantly propelled, by the vibration of the cilia that cover their surface. Many of them are dependent on the same current for their supplies of food; part of the water so introduced being taken into the stomach; and a part flowing over the respiratory surface. The higher tribes, how-

ever, go in search of their food, and have instruments of mastication for reducing it; but in these, as in the former, the anal orifice of the intestine opens into the same passage as that through which the current that has passed over the respiratory organs finds egress; so that the fœcal matter from the former, and the fluid that has served the purpose of the latter, are discharged together. Although very voracious, when supplies of food come in their way, most of the Mollusca are capable of fasting for long intervals, when none offer themselves,—a fact which is readily explained by that general inertness of their vital processes, which has been stated to be the characteristic of the group.

General characters of Articulata.

27. The members of the sub-kingdom Articulata are distinguished, for the most part, by characters which are exactly opposed to those just enumerated. Their characteristic form is easily defined; and in no instance is there any wide departure from it. The body is more or less elongated, and presents throughout a most exact bi-lateral symmetry. It is completely enclosed in an integument of greater density than the rest of the structure, which is divided into distinct rings or segments; these, being held together by a flexible membrane, allow considerable freedom of motion, whilst they firmly protect the soft parts, and afford attachment to numerous muscles. It is in the Centipede, and other such animals, that this division into segments is most distinctly and regularly marked. In the lower Articulata, such as the Leech and the Earth-worm, the integument is altogether so soft, that the intervals of the articulations are not very distinct from the rings themselves; and in the highest Crustacea and Arachnida, the segments are so closely united together, as to be in some instances scarcely recognisable. In the former, the movements of the body are entirely effected by its own flexion; whilst in the latter they are committed to members developed for that special purpose. These members also have an articulated external skeleton. The bulk of the body in the Articulata is made up of the muscles, by which the several segments, and their various appendages, are put in motion; these muscles have their fixed points on the interior of the hard envelope, just as they are attached in vertebrated animals to the exterior of the bones; and they form a system of great complexity.

28. The development of the organs of nutrition in Articulata would seem to be altogether subservient to that of the locomotive apparatus,—their function being chiefly to supply the muscles with the aliment necessary to maintain their vigour. The power of these muscles is so great in proportion to their size, that, in energy and rapidity of movement, some of the Articulated tribes surpass all other animals. These movements are directed by organs of sensation, which, although not developed on so high a plan as those of some Mollusca, are evidently very acute in their powers. There are very few instances of Articulated animals being in any way restrained as to freedom of locomotion; and these are found in a single group, the Cirrhopoda or Barnacle tribe, which connects this sub-kingdom with the last. In general, they roam freely abroad in search of food, and are supplied with prehensile organs for capturing their prey, and with a complex masticating apparatus for reducing it. Their actions are evidently directed almost solely by *instinctive* propensities, which are adapted to meet every ordinary contingency, being of similar character in each individual of the same species, and presenting but little appearance of ever being modified by intelligence. Hence these animals seem like machines, contrived to execute a certain set

of operations; many of them producing immediate results, which even man, by the highest efforts of his reason, has found it difficult to attain.*

29. All the Articulata, save a few of the very lowest species, possess a distinct head at one end of the body, furnished with organs of special sensation, and with lateral jaws for the prehension and reduction of food; and their movements, being principally guided by the special senses, take place in this direction. The bi-lateral symmetry of the body is not confined to its exterior; for it prevails most completely in the whole muscular apparatus; and even the organs of nutrition present more distinct traces of it than are to be seen elsewhere. The compact heart of the Mollusca, for instance, is here replaced by a long tube, the *dorsal vessel*, placed on the median line; and the respiratory organs, which are usually diffused through the whole system, are uniform on the two sides. Even the intestinal canal partakes of this symmetry; in some species it runs straight from end to end of the body; and where it does not throughout, its appendages are nearly equal on the two sides. The respiration of this group is for the most part aerial; and the apparatus for the purpose consists of a series of chambers or tubes, which are dispersed or extended through the whole body. By this means, the air, the blood, and the tissue to be nourished, are all brought into contact at the same points; and a much less vigorous circulation is required, therefore, than would otherwise be needed. The whole apparatus of nutrition is comprised within a comparatively small part of the body; and the bulk of the organs which compose it is never at all to be compared with that which we ordinarily find in the Mollusca. Thus, the liver, which in the Oyster forms a large part of the whole substance, is often scarcely recognisable as such in the insect; and the intestinal tube seldom makes many convolutions in its course from one extremity to the other. The blood is usually white, as in the other Invertebrated classes; but it contains a larger number of corpuscles than are seen in that of most of the Mollusca. The temperature varies to a certain degree with that of the atmosphere; but there are many insects that have the power of generating a large amount of independent heat, which is strictly proportionable to the quantity of oxygen converted by them into carbonic acid in the respiratory process. All the actions of the Articulata are performed with great energy; and, at the time of the most rapid increase of the body, the demand for food is so great, that a short suspension of the supply of aliment is fatal. They are capable, however, of being submitted to the influence of very extreme temperatures, with little permanent injury.

30. The adjoining figure, which displays the muscular apparatus of the interior of the body of a Cock-chafer, will give an idea of its complexity and variety, and of the large portion of the trunk which is occupied by it; and will also show the division of the skeleton into segments, the number of which in Insects is limited to thirteen. These are nearly equal and similar to each other in the larva; but, in the perfect insect, the three behind the head are united into the thorax, to which the legs and wings are attached; and the remainder form the abdomen, which has little concern in locomotion.

* Reference is here especially made to the celebrated problem of Maraldi, in regard to the angle at which the three planes, forming the bottom of the Bee's cell, should meet each other, so as to have the greatest strength, with the least expenditure of material.

Fig. 4.

Section of the trunk of *Melolontha vulgaris* (after Straus Durckheim), showing the complexity of the muscular system. The first segment of the thorax (3) is chiefly occupied by the muscles of the head, and those of the first pair of legs. The second and third segments contain the very large muscles of the wings and those of the other two pairs of legs. The chief muscles of the abdomen are long dorsal and abdominal recti, which move the several segments one upon the other.

General characters of Vertebrata.

31. In none of the three preceding divisions of the Animal kingdom, does the Nervous System attain such a degree of development, as to give it that predominance in the whole fabric, which it evidently attains in VERTEBRATA. In the Radiata and Mollusca, its functions are evidently restricted to the maintenance of the nutritive operations; and to the guidance of the animal, by means of its sensory endowments, in the choice of food, as well as (in some instances) in the search for an individual of the opposite sex: in the Articulata, its purpose appears similar, but is carried into effect in a different manner, the locomotive organs being the parts chiefly supplied by it. In the Vertebrata, on the other hand, the development of all the other organs appears to be subordinate to that of the Nervous System; *their* object being solely to give to *it* the means of the exercise of its powers. This statement is not, of course, as applicable to the lower Vertebrata, as it is to the higher; but it is intended to express the *general* character of the group. The predominance of the nervous system is manifested, not only in the increased size of its centres, but also in the special provision which we here find, for the protection of these from injury. In the invertebrated classes, wherever the nervous system is enclosed in any protective envelope, that envelope serves equally for the protection of the whole body. This is the case, for example, in regard to the spiny integument of the Star-Fish, the shell of the Mollusca, and the firm jointed rings of the Insect. The only exceptions occur in a few tribes, in which the nervous system is much concentrated; and in which the general organization approaches that of the Vertebrata.* In vertebrated animals, we find that the skeleton essentially consists of a series of parts destined to enclose the nervous centres, and to give attach-

* Thus, in the highest Crustacea, there is an internal projection from the shell, on each side of the median line, which forms a sort of arch enclosing the ventral cord; and in the naked Cephalopoda, the nervous centres are supported, and in part protected, by cartilaginous plates, which are evidently the rudiments of the internal skeleton of the Vertebrata.

ment on their exterior to the muscles by which the body is moved. It consists either of bone or cartilage; both of which structures are permeated by blood-vessels, absorbents, &c., and are capable of undergoing interstitial change, so as to be essentially different from the extra-vascular skeletons of the Invertebrata. The latter, when *external* (as they usually are), may be properly spoken of under the appellation of *dermo-skeleton;* being formed in some manner from the general integument. The former, being especially destined for the protection of the nervous system, may be termed the neuro-skeleton.

32. In considering the essential character of the skeleton of Vertebrata, we should look at its simplest forms,—those in which it has the least number of superadded parts. We find these in the serpent tribe among reptiles, and in the eel and its allies among fish. If we examine their skeletons, we perceive that the spinal column, with the cranium at its anterior extremity, constitutes the essential part of the vertebrated framework; and that the development of members is secondary to this. This spinal column usually consists of a number of distinct bones, the vertebræ; each of which is perforated by a large aperture, in such a manner that, when the whole is united, a continuous tube is formed for the lodgment of the spinal cord. The cranium, which it bears at its upper end, is in reality formed of the same elements as the vertebræ, instead of differing from them completely in structure, as we might be led to suppose by examination of its most developed forms only. The object of this enlargement is to enclose the brain, or mass of cephalic ganglia, which attains a greatly increased size in the Vertebrata; and also to afford support and protection to the organs of special sense, which are far more highly developed than elsewhere. The true nature of the cranium is best seen in those animals, in which the brain bears but a small proportion to the spinal cord, such as the lower reptiles and fishes; and an examination of its structure in these satisfactorily proves the reality of this view, which is further borne out by the history of its development, and of that of its contained parts, in the higher Vertebrata.

33. The vertebral column, at its opposite extremity, is usually contracted instead of being dilated,—forming a tail, or a rudiment of one, from which the nervous centres are entirely withdrawn; the development of the tail is commonly seen to be in an inverse proportion to that of the cranium. To this column, the ribs and extremities are merely appendages, which we find more or less developed in the various tribes, and often entirely absent; whilst the vertebral column is never wanting, although reduced in some species to a very rudimentary state. It is interesting to compare its various conditions, with those which have been noticed in the external skeleton of the Articulata. In the lowest animals of the group, locomotion is almost or entirely performed by flexion of the body itself; and here, as in the worm tribe, we find the skeleton extremely flexible, the whole being comparatively soft, and its divisions indistinct. This is the case, for example, in the lamprey and other Cyclostome fishes; in which there is no distinct division into vertebræ, the spinal column scarcely possessing even the density of cartilage. In proportion, however, as distinct members are developed, and the power of locomotion is committed to them, we find the firmness of the spinal column increasing, and its flexibility diminishing; and in birds,—in which, as in insects, the movements of the body through the air are effected by muscles which must have very firm points of support,—the vertebral column is much consolidated by the union of its different parts, so as to form a solid framework. As a general rule, then, the mobility of the extremities, and the firmness of the vertebral column, are in an inverse

ratio to each other. The number of these extremities in Vertebrata never exceeds *four;* and two of these are not unfrequently absent. The power of locomotion is not developed to nearly the same proportional extent as in the Articulata; the swiftest bird, for example, not passing through nearly so many times its own length in the same period, as a large proportion of the insect tribes: but it is far greater than that which is characteristic of the Mollusca; and there is no species that is fixed to one spot, without the power of changing its place. On the other hand, the highest Mollusca approach them very nearly in the development of organs of special sense, of which Vertebrata almost invariably possess all four kinds,—sight, hearing, smell, and taste.

34. The perfection of the articulate structure has been shown to consist in the development of those powers, which enable the animal to perform actions denoting the highest *instinctive* faculties. That of the Vertebrata evidently tends to remove the animal from the dominion of undiscerning, uncontrollable instinct, and to place all its operations under the dominion of an *intelligent* will. We no longer witness in these operations that uniformity, which has been mentioned as so remarkable a characteristic of instinctive actions. There is evidently, among the higher Vertebrata especially, a power of choice and of determination, guided by a perception of the nature of the object to be attained, and of the means to be employed, constituting the simplest form of the reasoning faculty; and the amount of this bears so close a relation with the development of the brain, that it is scarcely possible to regard them as unconnected. In Man, whose brain is far larger in proportion to his size, as well as more complex in its structure, than that of any other animal, the reasoning faculties attain the highest perfection that we know to be anywhere manifested by them in connection with a material instrument; the instinctive propensities are placed under their subjection; and all his acts, excepting those immediately required for the maintenance of his organic functions, are placed under their control. It is to man, therefore, that what was just now stated, of the predominance of the nervous system in Vertebrata, particularly applies; but the same may be noticed, though in a less striking degree, throughout the group. Not only is the influence of the nervous system to be traced in the sensible movements which they perform, but also in various modifications of the organic functions, which take place under the influence of particular states of mind, and the occurrence of which there is no reason to suspect in the lower tribes of animals. These are even much more striking in man than in the lower Vertebrata; indeed the comparative slightness of the influence of the mind upon the body is one of the causes, which render the lower Mammalia more able than man is, to recover from the effects of severe injuries. The Mollusca seem to grow like plants; their massive organs increasing by their own separate vitality, and being but little dependent upon each other. Even the act of respiration, which is in most animals performed by a series of distinct muscular contractions, is there principally effected through the medium of the cilia which clothe the respiratory surface. But in the Vertebrata the nervous system possesses a distinct and independent rank; its offices are those which more particularly constitute the active life of the animal; the organic functions have for their chief object, the maintenance of the nervous and muscular apparatus in the conditions requisite for their activity; and in consequence, all these different kinds of apparatus are so interwoven together, that their mutual dependence is very close.

35. The foregoing remarks will be found to have an important bearing

on the details subsequently to be given, respecting the functions of the nervous system in man; and it is desirable to set out with clear ideas on this subject, since there is no department of Physiology, regarding which more error is prevalent. There is no valid reason for believing, that the organic functions in animals, any more than the corresponding parts in plants, are *dependent* on the nervous system for their performance; but common observation shows that they are much influenced by it in the higher animals; and from such a comparison as that which has been just now briefly made, it would appear that, the higher the general development of the nervous system, the closer is their relation with it.

36. This general character of the Vertebrata harmonizes well with what may be observed, on a cursory glance at the structure of their bodies, of the proportion between the organs of nutritive and those of animal life. The former, contained in the cavities of the trunk, are highly developed: but, as in the Mollusca, they are for the most part unsymmetrically disposed. Of the latter, the nervous system and organs of the senses occupy the head; whilst the muscles of locomotion are principally connected with the extremities; both are symmetrical, as in the Articulata; but, whilst that part of the nervous centres, which is the instrument of reason, is very largely developed, the portion which is specially destined to locomotion, together with the muscular system itself, bears much the same proportion to the whole bulk of the body, as it does in the Articulated series. Hence we observe that the Vertebrata unite the unsymmetrical apparatus of nutrition characteristic of the Mollusca, with the symmetrical system of nerves and muscles of locomotion, which is the prominent characteristic of the Articulata; both, however, being rendered subordinate to the great purpose to be attained in their fabric,—the development of an organ through which intelligence peculiarly manifests itself. For the operations of this, a degree of *general* perfection is required, which is not met with elsewhere. The higher Vertebrata have a power of constantly keeping the temperature of the body up to a point, which it can only occasionally, and under peculiar circumstances, attain in the Articulata, and which it never reaches in the Mollusca. This involves an energetic performance of the functions of respiration and circulation; and these again require considerable activity of digestion. All the Vertebrata have red blood, which is propelled through the system by a distinct muscular heart; and the number of corpuscles which any given amount of the fluid contains, bears a nearly constant proportion to the ordinary temperature of the animal. They are further distinguished from Articulata by a character which seems of little importance, but which is very constant in each group. Whilst the mouth of the latter is furnished with two or three pairs of jaws which open *sideways*, that of the latter has never more than one pair of jaws, which are placed one above or before the other; and these jaws are usually armed with teeth, which are very analogous in their structure to bone.

General characters of Fishes.

37. The Vertebrata are subdivided into classes, principally according to their mode of performing the functions of respiration and reproduction. Thus, FISHES are at once separated from all other groups, from the circumstance of their being adapted, like the aquatic Invertebrata, to aerate their blood by gills; and being hence enabled to inhabit water during their whole lives, without the necessity of coming to the surface to breathe. The low amount of their respiration prevents their bodies from ever attaining a tem-

perature much above that of the surrounding medium; hence they are spoken of as cold-blooded. Further, they are oviparous; an ovum or egg being deposited by the parent, from which, in due time, the young makes its way; or if, as sometimes happens, the ovum is retained within the body of the parent until it is hatched, the young animal, though produced alive, is not subsequently dependent upon its parent for support. In many respects, the organization of Fishes is not much advanced beyond that of the higher Mollusca. Their respiratory apparatus has the same character; and the organs by which the blood is depurated of its superfluous azote, rather correspond with the temporary Corpora Wolffiana of higher animals, than with their true kidneys. The vertebral column itself is often very imperfectly developed; in a large proportion of the group, the skeleton is cartilaginous only; and in the lowest species it does not even manifest a distinct division into vertebræ. Living habitually in an element which is nearly of the same specific gravity with their own bodies, fishes have no weight to support, and have only to propel themselves through the water. Accordingly we find their structure adapted rather for great freedom of motion, than for firmness and solidity; and as progressive motion is chiefly effected by the lateral action of the spine, the vertebræ are so united as to move very readily upon one another. Instead of being articulated together by surfaces nearly flat, as in Mammalia, or by ball-and-socket joints, as in serpents, they have both their surfaces concave; and these glide over a bag of fluid (the representative of the intervertebral substance in the higher animals) which is interposed between each pair. The tail is flattened vertically; so as, by its lateral stroke, to propel the fish through the water. By this character, true fishes are distinguished from the aquatic Mammalia which are adapted to inhabit their element, and which commonly receive the same designation; for the latter, being air-breathing animals, are obliged to come frequently to the surface to respire, and their tail is flattened horizontally to enable them to do this with facility. The lateral surface of the body of Fish is further extended above, by the projection of the dorsal fin, which is supported on prolongations of the spines of the vertebræ; and below, by the abdominal fin, which also is placed on the median line: these will, of course, increase the power of the lateral stroke of the body, and can only be moved with the spine. The pectoral and ventral fins, on the other hand,—the former of which answer to the superior extremities, and the latter to the inferior extremities, of man,—serve, by their independent movements, rather as steering than as propelling organs; and they also assist in raising and depressing the animal through the water. The scales with which the bodies of all fishes are covered, are frequently of a bony hardness, and sometimes form a firmly-jointed casing, in which the trunk is completely enclosed; this is especially the case when the internal skeleton is imperfectly developed; so that here we have approach to the character of the Invertebrata.

38. The swimming-bladder, as it is commonly termed, of the fish, is not an organ *sui generis;* but is ascertained, by comparison with the pulmonary sacs of the lower reptiles, to be a rudimentary lung. It does not, however, give any assistance in the aeration of the blood, except in a few instances; but seems to be in general subservient to the elevation and depression of the body in its element. The heart of the fish is extremely simple in its construction, containing two cavities only; and the course of the circulation is equally simple. The blood which returns from the body in a venous condition, is received into the single auricle or recipient cavity; and from this it passes into the ventricle or propellent cavity. The latter forces it into a large trunk, which subdivides into branches that are distri-

buted to the branchial arches on each side; and in these it undergoes aeration. Being collected from the gills by returning vessels, the blood, now become arterial in its character, is transmitted to the large systemic trunk, the aorta, by which it is distributed through the system,—returning again to the heart, when it has passed through the organs and tissues of the body. Hence it is evident that the whole of the blood passes through the gills, before it goes a second time to the system; by which the imperfection of the aerating process itself is in some degree compensated. There is a special provision, too, for renewing by muscular power the stratum of water in contact with the gills; continual currents being sent over them from the pharynx, with which their cavity communicates. It is worth noticing that whilst, in the osseous fishes, there is a single large external gill opening on either side, with a valve-like operculum or gill-cover, there are, in the cartilaginous fishes, several slits on each side of the neck, one corresponding with each branchial arch. Similar apertures may be seen in the embryo of Man and of other Mammalia, as well as of birds and reptiles, at the time that the circulation is in the condition of that of the fish, the heart possessing only two cavities, and the blood being first propelled through a series of branchial arches.

General characters of Reptiles.

39. The class of REPTILES is oviparous and cold-blooded, like that of Fishes; but the animals belonging to it are formed to breathe air and to inhabit the surface of the earth,—the few which are adapted to make the water their dwelling, being obliged to come to the surface to breathe. Although they breathe air, however, their respiration is not usually so energetic as that of fishes; and their general activity is much less. The heart possesses three cavities, one of which receives the blood from the lungs, and another from the general system; the arterial and venous blood contained in these two auricles respectively, are transmitted to the third or propelling cavity, the ventricle, where they are mixed; and the half-arterialized fluid is then transmitted to the system at large, a part being sent to the lungs. Thus only a portion of the blood expelled from the heart is exposed to the influence of the air; and that which is transmitted to the body is very imperfectly arterialized. In some of the higher Reptiles, as the Crocodile, the ventricle is double, as in the superior Vertebrata; and the course of the circulation is so arranged, that pure arterial blood shall go to the head, where it is most required, whilst a mixed fluid is sent to the rest of the body. This plan exactly corresponds with the one which is adopted in the circulation of the human fœtus, from the time of the formation of the four cavities in its heart, and of the permanent system of vessels, up to the period of birth. The imperfect arterialization of the blood in Reptiles causes a great degree of general inertness in their various functions. Their motions are principally confined to crawling and swimming; their general habits are sluggish, and their sensations are obtuse; and their nutritive functions are very slowly performed. Hence they can exist for a long time with a very feeble exercise of these functions, under circumstances that would be fatal to animals in which they are performed with greater activity. In cold and temperate climates, they pass the whole winter in a state of torpidity; and at other seasons, they may be kept during a long time from their due supplies of food and air, without appearing to suffer much inconvenience.

40. In regard to the structure of their skeleton, and the external form of

the body, there is a considerable difference among the several orders of Reptiles. Thus, *Tortoises*, *Lizards*, and *Serpents* differ from each other so widely, that a common observer would separate them completely; and yet they not only agree in all the foregoing characters, but pass into one another by links of transition so gradual, that it is even difficult to classify them. They differ, however, more in the configuration of the accessory parts, than in the structure of the essential portion of the skeleton,—the spinal column. This is characterized by the ball-and-socket articulation of the vertebræ, each vertebra having one surface convex, and the other concave,—a structure which is more strongly marked in serpents, whose movements are performed chiefly by the flexion of the spinal column itself, than it is in the other tribes. The chief characteristic of the *Tortoise* tribe is the *shell* or case in which the body is contained. The upper arch of this shell, termed the carapace, is formed by a bony expansion from the edges of the ribs, which is covered by a set of horny plates that are to be regarded (like smaller scales) as epidermic appendages. The under portion, termed the plastron, is composed of the sternum, which is in like manner extended laterally. In the land-tortoises, this usually forms a complete floor; but in the aquatic species, a part is commonly absent, the interval being filled up by cartilage and membrane. The skeleton of the Lizards is formed more upon the general plan of that of Mammalia, but may be readily distinguished from it. The sternum is usually prolonged over the front of the abdomen, and the ribs are continued through a much larger part of the spinal column; of these abdominal ribs, the white lines across the recti muscles in the higher Vertebrata are evidently the rudiments. In the higher lizards, the power of locomotion is almost entirely delegated to the extremities; but in the less typical species, the body and tail are much prolonged, so as to present a serpentiform aspect; and first one pair of feet, and then the other, disappear, until the form is altogether that of the serpent. Even in Serpents, however, rudiments of extremities are frequently to be found; but there mode of progression is very different, and these rudiments are of no assistance to them. The most remarkable feature in the serpent's skeleton, besides the absence of legs, and the large number of ribs and vertebræ, is the deficiency of a sternum; through the absence of this, the extremities of the ribs are free, and they become in fact the fixed points, on which the animal crawls, when advancing slowly forwards.

41. Although the configuration of the cranium varies much in the different orders of Reptiles, yet there is a remarkable agreement in certain general characters, and in the general *degree* of development. It consists of a much larger number of parts than are to be found in the cranium of adult Birds or Mammalia, each principal bone being subdivided, as it were, into smaller ones. This condition exactly corresponds with that which may be observed during the process of ossification in higher Vertebrata; for each of the larger bones of the cranium is formed from several centres of ossification; so that, if the cranium of a fœtus or young infant be macerated, it will fall into a number of pieces nearly corresponding with those of the reptile's skull. The different orders of Reptiles have a close agreement in various other points; especially in the degree of development of their several organs of nutrition. Thus in all of them, the lungs, though commonly of large size, are so little subdivided as really to expose but a small extent of surface. The glandular structures, too, are formed upon a much more simple type than is characteristic of the warm-blooded Vertebrata. They all agree, moreover, in having the body covered with scales; which, though generally small, are sometimes large flattened plates.

42. Between Fishes and true Reptiles, there is a group which remarkably combines the characters of both; being composed of animals that come forth from the egg in the condition of fishes; but which afterwards attain a form and structure closely corresponding with that of true reptiles. This group, consisting of the Frog and its allies, is sometimes associated as an order (*Batrachia*) of the class of Reptiles; and is sometimes made to rank as a distinct class, the Amphibia. The Tadpole or larva of the frog is in every essential respect a fish. Its respiration and circulation, its digestion and nutrition, its locomotion and sensation, are entirely accordant with those of fishes. The body is destitute of members for progression, but is propelled through the water by the lateral undulations of the spinal column, which is articulated in the same manner as is that of fishes. At a certain period, a metamorphosis commences, in which almost every organ in the body undergoes an essential change. Lungs are developed, which take the place (in regard to their function) of the gills; and the latter are atrophied. The auricle of the heart is divided into two; and the circulation is performed on the plan of that of the true reptile. Two pairs of members are usually formed, to which, when they are fully developed, the power of progression is committed,—the tail disappearing; in some species, however, the tail remains, and the extremities are small. The digestive system undergoes a remarkable alteration,—the intestinal canal, which was previously of enormous length in proportion to the body, being now considerably shortened, in accordance with the different kind of food on which the animal has to subsist. The mode of articulation of the spinal column, also, undergoes a change, which brings it to the type of that of reptiles. On the whole, there scarcely appears sufficient reason for separating these animals, in their adult condition, from the class of Reptiles. The most important point of difference is the nakedness of the skin, by which the Batrachia may be at once distinguished, even when their external configuration approaches that of reptiles in general. In this manner, the common *Salamander* or Water-newt may be recognised as belonging to this group, though we should otherwise have placed it among the Lizards; and the *Cæcilia*, which has the form of the serpent, is in like manner known to be really allied to the frog. An acquaintance with the history of these animals confirms such an arrangement, by showing that the Salamander and the Cœcilia* undergo a metamorphosis; breathing by gills, and having the general structure of fishes, in the early part of their lives.

43. Besides those animals, however, which attain the condition of perfect reptiles, this group contains several whose development is arrested, as it were, in an intermediate or transition state; their adult form presenting a remarkable mixture of the characters of the two classes which they thus connect. This is the case in the *Proteus*, *Siren*, and other less known animals, which retain their gills through the whole of their lives, whilst their lungs are at the same time developed; so that, as they can respire either air or water, they are the only true *amphibious* animals. In their entire organization, they correspond with the tadpole of the frog at an advanced period of its metamorphosis; and it is a most interesting fact (which has been established by the experiments of Dr. W. F. Edwards) that, if tadpoles be kept in such a manner as to be freely supplied with food and exposed to a constantly-renewed current of water, but be secluded from light and from the direct influence of the solar heat, they will continue to grow as tadpoles;

* This fact, in regard to the *Cæcilia*, has only been recently substantiated. See Annals of Natural History, May 1841.

their metamorphosis being checked. The metamorphosis of the Batrachia closely corresponds with that of Insects; the young animal, in each case, at the time of its emersion from the egg, having a resemblance in all essential particulars to a class below that to which it is ultimately to belong. This kind of metamorphosis is by no means confined to them, however; for the gradual extension of our knowledge of the early history of different tribes of animals, is constantly bringing to light new facts of the same kind. The Polypes and lower Mollusca, for instance, come forth from the egg, and swim about for some time, in a condition which can scarcely be termed *animal;* for there is not even a mouth leading to a digestive cavity, nor are there any other organs of locomotion than the cilia, the action of which is involuntary. And, in tracing the development of the human embryo, we shall find that it undergoes a series of progressive changes equally remarkable;—the principal difference being, that these changes are not so arranged in harmony with each other, as to cause the embryo to present at any one time the combination of characters which belong to the Fish, Reptile, &c., or to enable it to sustain an independent existence.

General characters of Birds.

44. From Reptiles to BIRDS the transition would seem rather abrupt, since the latter class is, in almost every respect, the opposite of the former. Nevertheless it would seem to have been effected by the now extinct Pterodactylus, which combined in a most remarkable degree the characters of the two groups. Birds are, like fishes and reptiles, *oviparous* Vertebrata; but they differ essentially from both, in being themselves warm-blooded, and in the assistance which they afford by their own heat in the development of the ovum. Birds correspond with Mammalia in possessing a heart with four cavities, and a complete double circulation; by which the whole of the blood that has circulated through the body is exposed to the influence of the air, before being again transmitted to the system. This high amount of oxygenation of the blood is accompanied by great activity and energy of all the organic functions, acuteness of the senses, and rapid and powerful locomotion; as well as by the evolution of a degree of heat, superior to that which we ordinarily meet with among the Mammalia. The temperature of birds ranges from about 140° to 112°. The lowest is in the aquatic species, whose general activity is much less than that of the tribes which spend most of their time in the air; the highest is among those distinguished for the rapidity and energy of their flight, such as the Swallow.

45. Birds have been denominated, and not inappropriately, the Insects of the vertebrated series. As in the animals of that class, we find the whole structure peculiarly adapted to motion, not in water, nor supported by solid ground, but in the elastic and yielding air. It is impossible to conceive any more beautiful series of adaptations of structure to conditions of existence, than that which is exhibited in the conformation of the Bird, with reference to its intended mode of life. In order to adapt the vertebrated animal to its aerial residence, its body must be rendered of as low specific gravity as possible. It is further necessary that the surface should be capable of being greatly extended; and this by some kind of appendage that should be extremely light, and at the same time possessed of considerable resistance. The degree of muscular power required for support and propulsion in the air involves the necessity of a very high amount of respiration, for which it has been seen that an express provision exists in Insects; and as the general activity of the vital processes depends greatly upon the high temperature

which this energetic respiration keeps up, a provision is required for keeping in this heat, and not allowing it to be carried away by the atmosphere through which the bird is rapidly flying.

46. The first and third of these objects,—the lightening of the body, and the extension of the respiratory surface,—are beautifully fulfilled in a mode, which will be found to correspond with the plan adopted for the same purpose in insects. The air which enters the body is not restricted to a single pair of air-sacs or lungs placed near the throat, but is transmitted from the true lungs to a series of large air-cells disposed in the abdomen and in various other parts of the body. Even the interior of the bones is made subservient to the same purpose, being hollow and lined with a delicate membrane, over which the blood-vessels are minutely distributed. In this manner, the respiratory surface is greatly extended; whilst, by the large quantity of air introduced into the mass, its specific gravity is diminished. The subservience of the cavities in the bones to the respiratory function, is curiously shown by the fact, which has been ascertained both accidentally and by a designed experiment, that, if the trachea of a bird be tied, and an aperture be made in one of the long bones, it will respire through this.

47. The other two objects,—the extension of the surface, and the retention of the heat within the body,—are also accomplished in combination, by a most beautiful and refined contrivance, the covering of feathers. Like hair or scales, feathers are to be regarded as appendages to the cutis; the stem is formed from it by an apparatus, which may be likened to a hair-bulb on a very large scale; but there are some additional parts for the production of the laminæ, which form the vane of the feather, and which are joined to the stem during its development. These laminæ, when perfectly formed, are connected by minute barbs at their edges, which hook into one another, and thus give the necessary means of resistance to the air. The substance of which feathers consist is a very bad conductor of heat; and when they are lying one over the other, small quantities of air are included, which still further obstruct its transmission by their non-conducting power. Thus the two chief objects are fulfilled;—power of resistance and slow conducting properties being obtained in combination with lightness and elasticity. At the two extremes of the class, however, we meet with remarkable modifications in the typical structure of feathers. In the Penguin, those which cover the surface of the wings have a strong resemblance to scales; and the wings are not employed to raise this bird in the air, but only to propel it (as fins would do) by their action on the water. On the other hand, in the Ostrich tribe, the laminæ of the feather are quite distinct from each other; and no longer form a continuous surface; so that the feathers more resemble branching hairs. Here the wings are almost or completely absent, the birds of this tribe being constantly upon the ground, propelling themselves by running, and approaching the Mammalia in many points of their conformation.

48. The bony framework of Birds presents many remarkable adaptations to the same purposes. In the first place it is to be remarked, that the faculty of locomotion is here entirely delegated to the extremities, and that the skeleton of the trunk must be consolidated in proportion to the power with which they are to be endowed, in order to afford their muscles a firm attachment. Just as the segments of the external skeleton of the Articulata, therefore, are consolidated in Insects, do we find that the vertebral column and its appendages are firmly knit together in the upper part of the trunk of Birds. The vertebræ are closely united to each other; and the ribs are united to the sternum by bony prolongations of the latter, instead of by car-

tilages. This union is so arranged, that the state of expansion is natural to the thorax, whilst that of contraction is forced. Reptiles possess but a very imperfect mechanism for inflating their lungs. Being destitute of a diaphragm, they are obliged to force air into the chest by a process resembling deglutition; so that, strange as it may appear, a reptile may be suffocated by holding its mouth open. The diaphragm is absent among birds, as among reptiles; except in a few species which most nearly approach the Mammalia. But its deficiency is compensated by this contrivance, which keeps the lungs and air-sacs always full except when the bird, by a muscular effort, expels the air from them, in order that they may be re-filled by a fresh supply. By this means, also, the specific gravity of the body is more constantly diminished, than it could be if the lungs had been subjected to the constantly alternating contractions and expansions which they perform in Mammalia. It is worthy of remark, that the air which enters the bones and the air-sacs, passes through the lungs, both on its entrance and return, so as to yield to their capillaries all the oxygen they can take from it, of which the blood that it has elsewhere met with has not deprived it. It is only in the lungs that it meets with purely venous blood; for they alone receive the branches of the pulmonary artery; the vessels which are distributed upon the respiratory surface of the air-sacs and bones being a part of the systemic circulating apparatus. Hence we may regard this curious provision as being partly designed for the aeration of the blood in its course through the system (this, it will be remembered, is the sole mode in which the function is performed in insects); and partly for supplying the lungs with air as from a reservoir, during the violent actions of flight.

49. The articulation of the anterior extremity with the trunk exhibits a peculiar provision for strength and power, which we find in no other Vertebrata. The two clavicles are united together on the central line, forming the *furcula* or merry-thought; and the use of this is to keep the shoulders apart, notwithstanding the opposing force exerted by the pectoral muscles in the action of flight. It is generally firm, and its angle open, in proportion to the power of the wings. Besides this bone, there is another connecting the sternum with the scapula on each side; this is the *coracoid* bone, which in Man and other Mammalia is scarcely developed, being merely a short process which does not reach the sternum. The sternum of birds usually exhibits a very remarkable development on the median line; an elevated keel or ridge being seen on it, which serves for the attachment of the powerful muscles that depress the wings. In the great development of the sternum, birds have some analogy with the Turtle tribe (which they also resemble in the deficiency of teeth, and in the development of a horny covering to the jaws); but in these, the lateral elements of the sternum are the parts most developed, whilst in birds it is the central portion which exhibits the peculiarity. From the depth of the keel of the sternum, a judgment may be formed of the thickness of the pectoral muscles, and thence of the powers of flight; in the Ostrich tribe, where the wings are not sufficiently developed to raise the bird off the ground, the sternum is quite flat, as in the Mammalia. The want of flexibility in the trunk is counterbalanced by the length and flexibility of the neck; the number of cervical vertebræ is very considerable, varying from 12 to 23,—the highest number being present in the Swan tribe. They are so articulated, that the head can be turned completely round, or moved in any direction. The anterior extremities of birds being solely adapted to sustain them in flight, the posterior are necessarily modified for their support on the ground. They are

usually placed rather far back; but the spine has a position more inclined than horizontal, so that the weight may not be altogether thrown forwards. The trunk is supported on the thighs by powerful muscles; and there is another series which passes from the lower part of the spine continuously to the toes, turning over the knee and heel, in such a manner that the flexion of these joints shall tighten the tendons; by this contrivance, the simple weight of the body flexes the toes, and birds are thus enabled to maintain their position during sleep, without any active muscular effort.

50. Not only do birds resemble insects in their general structure and mode of life, but also in the peculiar development of the *instinctive* powers. Under the direction of these, the place for their nests appears to be selected; their materials collected; the nests themselves built, and the young reared in them; the migrations are performed; and many curious stratagems are employed to obtain food. It is sufficient to indicate these in general terms; since it is well known that the habits of birds have peculiarities restricted to each species, and that in all the individuals of each species they are as precisely alike as their circumstances will admit. Nevertheless, there is observed in birds a degree and kind of adaptation to varying conditions, which insects do not possess, and which display an amount of *intelligence* far superior to what is found in that class. This is evinced also in their *educability;* for no animal can be taught to perform actions which are not natural to it, unless it possesses in a considerable degree the powers of memory and association at least, if not some of the higher mental faculties, such as the power of perceiving and comparing the relations of ideas. Moreover, in the *domesticability* of many tribes of birds, we see this educability combined with a degree of that higher form of attachment to man, which is so strikingly exhibited by certain species of Mammalia. The development of the senses of birds varies in different tribes, according to the mode in which they are adapted to obtain their prey. The sight is almost always extremely acute, and is their chief means of seeking food; and where this would be of comparatively little service, as in the nocturnal rapacious birds, it is compensated by a much higher development of the faculty of hearing, than is usual amongst other tribes. The senses of smell, taste, and touch, do not seem to be usually very acute in birds; but there are particular tribes in which each of these is more developed than in the rest.

51. As might be expected from their analogy with insects, the development of the organs of nutrition (excepting that of the respiratory organs) is much less striking in birds, than is that of the locomotive apparatus. The whole cavity of the trunk, especially in birds distinguished for their powers of flight, is small in comparison with that of the body; but what is wanting in the size of the organs, is made up in their energy of function. Hence the demand for food is more active in them, than in any other class of animals. It is interesting to observe, that there is more bi-lateral symmetry in the arrangement of the viscera, than we usually find in the higher Vertebrata. This is evidently connected with their active locomotive powers; as it is obviously necessary, that the two sides of the body should be balanced with perfect equality, and that their energy should be exactly correspondent. The lungs and air-sacs are precisely similar in size and situation on the two sides; consequently the heart is placed on the median line; and the mode of origin, from the aorta, of the trunks supplying the head and upper extremities, is alike on the two sides. The liver, also, is less asymmetrical than we usually find it in the Mammalia.

52. It has been remarked, that the assistance afforded by the parent, in

the development of the young, is greater in birds than in the lower Vertebrata, whilst it is less than in Mammalia. Whilst reptiles and fishes show little or no concern for their eggs after they have deposited them, birds sedulously tend them, affording them not only protection but warmth, by means of their powerful heat-producing apparatus. The yolk-bag of the bird's egg is so suspended in the midst of the white albumen, that, when the egg is laid upon its side, it will always rise to the highest part of it; and the relative weight of the several parts is further adjusted in such a manner, that the *cicatricula* or germ-spot shall always be at the point nearest the shell, so as to come into the closest proximity with the source of heat, and also to be in the most immediate relation with the surrounding air. There are some birds, inhabiting the equatorial regions, which do not always incubate their eggs, trusting to the solar heat for their maturation. It is said that the Ostriches of the intertropical deserts are content with covering their eggs with a thin layer of sand, so as to admit the action of the sun by day, and to keep them warm at night; but that those living under a less constantly elevated temperature, sit upon their eggs,—if not continually, at any rate when the solar heat is not sufficient. This statement has been disputed; but its truth seems to be confirmed by a curious observation made by Mr. Knight, that a Fly-catcher, which built for several years in one of his hot-houses, sat upon its eggs when the temperature was below 72°, but left them when it rose above that standard. The degree of assistance afforded by the parent birds to their young, after their emersion from the shell, varies much in different tribes; in general it may be remarked, however, that it is most prolonged in those which ultimately attain the highest development, and especially in those whose intelligence is the greatest. Thus the chicken and the duckling, when just hatched, are able to shift for themselves; but among the Raptorial and Insessorial birds, which rank far higher in the scale, the young is for a long time dependent upon the parent for food; and in the Parrot tribe, which unquestionabty surpasses all others in intelligence, the parent not only supplies its young with food which it has obtained for them, but partly nourishes them by a milky secretion from the interior of the craw, impregnating with this the aliment that it swallows, and afterwards disgorges for its offspring.

General characters of Mammalia.

53. The MAMMALIA are universally regarded as the highest group in the Animal kingdom; not only from being the one to which Man belongs (so far, at least, as his bodily structure is concerned), but also as possessing the most complex organization, adapted to perform the greatest number and variety of actions, and to execute these with the greatest intelligence. The contrast is here extremely strong between the *reasoning* and the *instinctive* powers, even when we put Man out of view. When we compare, for example, the sagacity of a Dog, Monkey, or Elephant, and the great variety of circumstances in which they will display an intelligent adaptation of means to ends, with the limited operations of the insect, over which the judgment and will seem to have no control, we cannot help being struck with the difference. The former are *educable* in the highest degree next to Man; the latter could not be made to change its habits, in any essential degree, by the most prolonged course of discipline; still the difference in this respect between Man and the most intelligent of other Mammalia is so strongly marked, that some naturalists have proposed to exclude him

altogether from the classification of this group, and even from the Animal kingdom. This is, however, by no means a philosophical plan; since the mind of Man is, in the present state of being, as closely connected with its material tenement, as we have any reason to believe that of brutes to be; and since there is no difference of *kind* between their faculties, that we have a right to assume as characteristic,—the difference being chiefly in degree. Man is like them actuated by instinctive propensities, which have an immediate bearing on his corporeal wants; and they have, like him, the power of adapting their actions to gain certain ends, of which they are conscious. A dog or an elephant may show more real wisdom, in controlling for a time its instinctive propensities, from the desire to accomplish some particular object, than is displayed by many men, who give free scope to the exercise of their sensual passions, although warned by reason of their injurious consequences.

54. This high development of the intelligence in Mammalia is evidently connected with the greatly-prolonged connection between the parent and the offspring, which we find characteristic of this class. Mammalia are, like Birds, warm-blooded Vertebrata, possessing a complete double circulation; and some of them are adapted to lead the life of birds, passing a large part of their time in darting through the air on wings, in pursuit of insect prey. But they differ from Birds in this essential particular, that they are not oviparous, but viviparous, producing their young alive,—that is, in a condition in which they can perform spontaneous movements, and can appropriate nourishment supplied to them from without. But they are not distinguished from all other animals by this character alone; for there are some species among Reptiles, Fishes, and even Insects, which produce their young alive,—the egg being retained within the oviduct and hatched there. The real distinction is that which the name of the class imports,—that the young are subsequently nourished by suckling. There is another distinction, which is not, however, equally applicable to the whole class. In all, the yolk-bag is very small in proportion to its size in birds; and the contents of the ovum, instead of furnishing (as in that class) the materials necessary for the development of the young animal, up to the time when it can ingest food for itself, only serve for the earliest set of changes in which this process consists. In all the later stages of the evolution of the embryo, it is supplied with nutriment directly imbibed from its parent. This is at first accomplished by means of a series of root-like tufts, which are prolonged from the surface of the ovum, and insinuate themselves among the maternal vessels, without, however, uniting with them. These tufts absorb from the maternal fluid the ingredients necessary for the support of the embryo, and also convey back to the parent its effete particles, which are received back into her blood and cast out of her system by the processes of secretion, respiration, &c.

55. The Mammalia may be divided into two sub-classes; in one of which the structure just described is the greatest advance ever made, in the apparatus by which the fœtus is nourished; whilst in the other, a more concentrated form is subsequently assumed by it. The ovum of the latter is delayed for a longer period, in a cavity formed by the union of the two oviducts, termed the *uterus;* which can be scarcely said to be developed in the Marsupialia and Monotremata, the two orders constituting the first sub-class. The vascular tufts proceeding from the chorion become especially developed at one point, and the vessels of the uterus are extremely enlarged in a corresponding situation; the tufts dip down, as it were, into a chamber formed by an extension of the inner lining of these vessels, and serve the combined

purpose of the roots of plants and of the branchiæ of aquatic animals,—absorbing from the maternal blood the materials required for the nourishment of the embryo, and aerating that of the fœtus by exposing it to the influence of the parents. The peculiar organ thus formed is termed the *placenta;* and the two sub-classes of the Mammalia have thence received the appellations of *placental* and *non-placental.* The animals belonging to the latter present many points of affinity to Birds, in the structure of their internal organs. That of the brain is very nearly allied in these two groups; and their amount of intelligence seems, as far can be determined, to bear a close correspondence. The *Ornithorhyncus* in particular, has so many marks of alliance to Birds, in its osteology, as well as in its horny bill, and in the spur on its hind legs (which resembles that of the Cock), that naturalists have much debated whether it could be really termed a mammiferous animal. No *positive* evidence has yet been obtained that its young are born alive; but on the other hand, there is strong reason to believe that they come into the world unenclosed in the ovum, although in a very imperfect condition. Moreover, it has been satisfactorily ascertained that the young are nourished, for some time after their birth, by a mammary secretion, which the organization of their mouth at that period enables them to obtain from the parent. In the Marsupialia, there is a remarkable compensation for the abrupt termination of the period of uterine gestation,—the young being received into a pouch or marsupium, within which the nipple is situated; this is extremely prolonged, and the mouth of the fœtus (for so it must still be considered) is adapted to receive and hold on by it; so that the little creature, which looks more like an earth-worm than a mammiferous animal, is thus suspended within the protective pouch, until its development is so far advanced, that it can shift for itself in the same degree as other new-born animals can do.

56. The period of gestation in the higher class of Mammalia, is usually prolonged until the fœtus is able, on its entrance into the world, to execute regular movements, some merely indicative of its desire for food, and others which are evidently designed for the acquirement of it. In many species, the young animal seems to be from the first in the full possession of its senses, and has considerable power of active locomotion; in general, however, it is very dependent upon its parent, only being able to obtain food when this is placed within its immediate grasp. Such is the case with the Human infant, which is dependent, more or less closely, upon its parent, during a larger proportion of its existence than is the young of any other animal. Here again, therefore, we perceive the application of the general law, that, the higher the grade of development a being is ultimately to assume, the more does it require to be assisted during the early stages of development. In the case of Man, the prolongation of this period has a most important and evident influence upon the social condition of the race; being, in fact, one of the chief means by which the solitary are bound together in families.

57. The class Mammalia, taken as a whole, is not characterized so much by the possession of any one particular faculty,—like that which has been seen in Birds,—as by the perfect combination of the different powers, which renders the animals belonging to it susceptible of a much greater variety of actions than any others can perform. There are none which can rival Birds in rapidity of locomotion; but there are few that cannot perform several different kinds of progression. There are none that can compete with Birds in power of sight; but there are few that do not possess the senses of smell, taste, and touch, in a more elevated degree. Several of these movements require a considerable amount of flexibility in the spine;

hence the vertebral column and the bony framework of the trunk are never so much consolidated as they are in Birds. On the other hand, the neck is much less moveable; it never consists of more than seven vertebræ, and these are always present, so that they are sometimes of great length, as in the Giraffe, and sometimes extremely short, as in the Whale, which seems to have no neck at all. In the greatest number of Mammalia, the body is supported upon all the four extremities, as in Reptiles, being adapted for progression along the surface of the earth. There are some species, however, in which the typical structure has undergone a metamorphosis, by which it is made to resemble that of a Bird; whilst in others it is modified so as to conform to the character of the Fish. In the Bats, the power of motion is almost entirely delegated to the wings, which are composed of skin stretched over a framework formed of the widely-extended hand. The sternum has a projecting keel for the attachment of the pectoral muscles, as in Birds. And in the Whale tribe, the power of locomotion is almost completely taken from the extremities and given back to the trunk, as in Fishes; for the posterior extremities are entirely absent, and the anterior serve only for guidance: there is this important difference, however, that the tail, which is flattened vertically in Fishes, is flattened horizontally in the Cetacea, which require the power of frequently coming to the surface to breathe.

58. The inferior energy of muscular movement in the Mammalia is accompanied by an inferior amount of respiration: the type of the respiratory apparatus, however, is higher than in Birds, a large extent of surface being comprised within a smaller space. The lungs are confined to the cavity of the thorax; and there is a provision for the regular renewal of the air received into them, by the action of the diaphragm, which here completely separates that cavity from the abdomen. The diminished amount of respiration, again, involves the production of a lower degree of animal heat; so that the temperature of this class seldom rises above 104°. There is therefore less need of means of effectually confining the caloric,—especially, too, as their greater size causes their radiating surface to be much less in proportion than that of Birds; and accordingly we find them provided only with a covering of hair or fur, which is much less warm than that of feathers, and which is thin and scanty in those which inhabit tropical climates. The chief exception to the last rule is in the case of the Sloths and of some Monkeys, which inhabit situations exposed to the most powerful rays of the sun, and which are covered with a long but thin and coarse hair, the purpose of which is evidently the protection of their skin from the external heat. The inferior energy of the respiration and circulation involve a diminished activity of the other functions of nutrition, as compared with those of Birds; and the demand for food appears to be somewhat less constant. Their various organs, however, are developed upon a higher plan, as we have already observed in regard to those of respiration.

Chief Subdivisions of Mammalia.

59. In subdividing the truly Viviparous division of the class, so as to separate Man from the tribes with which he is associated in it, we may be advantageously guided in the first place by the conformation of the extremities; since upon the perfection of the organs of touch will depend much of the address of an animal, in executing the actions to which it is prompted by its intelligence. The degree of this perfection is estimated by the number and mobility of the fingers, and the degree in which their extremities are enveloped by the nail, claw, or hoof that terminates them. When the

fingers are partly absent, or are consolidated together, and a hoof envelopes all that portion which touches the ground, it is obvious that the sensibility must be blunted, whilst at the same time the extremity becomes incapable of prehension. The opposite extreme is where a thin nail covers only one side of the extremity of the finger, leaving the other possessed of all its delicacy;—where several such fingers exist, of which one can be opposed to the rest, so as to render prehension more perfect, and to perform a great variety of actions;—and where the plane of the whole hand can be turned in any position, by the nature of its attachment to the forearm. Between these, there are many intermediate gradations. By these characters, the viviparous Mammalia may be divided into the *Unguiculated*, which have separate fingers, terminated by distinct nails or claws; and the *Ungulated*, in which the fingers are more or less consolidated, and enclosed at their extremity in a hard hoof. Hoofed animals are necessarily Herbivorous, inasmuch as the conformation of their feet precludes the possibility of their seizing a living prey; and they have flat-crowned grinding teeth for triturating their food. The summits of these teeth are usually not covered by a smooth coat of enamel, but present a series of elevations and depressions; these are occasioned by the peculiar structure of the teeth, which consist of alternating plates of enamel, ivory or dentine, and cementum or crusta petrosa; these are of three different degrees of hardness; and, as the softer portions will of course wear down first, the harder remain as projecting ridges. In order to give effect to these, there is usually a considerable power of lateral motion possessed by the lower jaw; so that a regular grinding action may be performed, which is favourable to the complete reduction of the tough vegetable substances that serve as their food.

60. Animals with Unguiculated fingers are capable of more variety in the character of their food. In some it is almost exclusively vegetable, as in the Rodentia; and here the power of prehension possessed by the extremities is small, the forearm not being so constructed as to be capable of the motions of pronation and supination. In this order, the mouth is remarkably adapted for grinding down hard vegetable substances,—the molar teeth being furnished with transverse ridges of enamel, and the jaws having a powerful movement backwards and forwards.* In others, again, there is an almost exclusive adaptation to animal food. The toes are furnished with long and sharp claws; and the fore-feet may be placed in a variety of positions, by the rotation of the two bones composing the lower part of the leg. The grinding teeth are very narrow, and are formed with sharp points and edges, so as to be adapted for dividing animal flesh; these are firmly set in short strong jaws, which are fitted together like the blades of a pair of scissors, having no action but a vertical one; and the constant friction of the edges of the molar teeth against each other, keeps them sharp.† In this group, too, we find the greatest development of the canine teeth, which are

* The action of trituration is chiefly performed by the external pterygoid muscles. When these are in operation together, they draw the whole of the lower jaw forwards, so as to make the lower teeth project beyond the upper; and the jaw being drawn back again by the digastric muscles, a rapid alternate movement may be thus effected, such as is seen in the Rodentia. When only the muscle of one side acts, the condyle of that side is thrown forwards; and by the alternating operation of the two, aided by other muscles, that rotatory motion is given which we see especially in Ruminating Quadrupeds.

† In Carnivorous animals, the muscles which elevate the lower jaw attain a very high degree of development. This is very remarkably seen in the internal pterygoid, which in Man is of subordinate size and importance, but which is a very powerful muscle in the Lion, Tiger, &c.

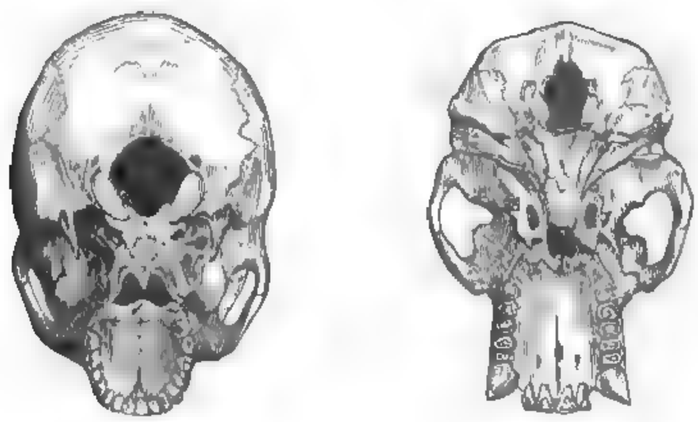
commonly absent, or but slightly developed, among herbivorous quadrupeds; these are the most powerful weapons with which Carnivorous animals are furnished, serving both for the first attack of their prey, and for subsequently tearing it in pieces. It is evident that the whole structure of the body must undergo modification in conformity with the nature of the food. The simple stomach and intestinal canal of the carnivorous animal, adapted only to the digestion of aliment consisting of materials similar to those of its own body, would be totally useless to an animal prevented by its general organization from obtaining any other than vegetable food; and on the other hand, the teeth and hoofs of the herbivorous quadruped would be of little assistance to an animal whose instincts and general conformation adapted it for the pursuit of animal prey. It will be presently seen that, in regard to his organization, Man holds an intermediate place between the purely herbivorous and purely carnivorous tribes, being capable of subsisting exclusively upon either kind of diet, but being obviously intended by nature to employ both in combination.

61. The classification of the Mammalia by Linnæus, although not strictly natural, affords us the readiest means of separating Man, zoologically, from all other animals. He arranged under his order *Primates*, all the unguiculated Mammalia, which have four incisor teeth and two canines in each jaw; and thus Man, with the Monkeys and the Bats, was distinguished from the remainder of those Quadrupeds that have separate fingers with distinct nails or claws. This group is now subdivided into three orders, corresponding with the Linnæan genera, *Homo*, *Simia*, and *Vespertilio*. The last of these orders, named *Cheiroptera*, includes the Bat tribe, which is easily separated from all others, by the peculiar conformation of the anterior extremities, from which its name is derived. The second, termed *Quadrumana*, comprehends the Apes, Monkeys, and Baboons, which exhibit a regular series,—the highest approaching Man in general conformation, and the lowest having much more of the general organization of the inferior carnivorous quadrupeds. They are distinguished from other viviparous Mammalia, by possessing an opposable thumb on all four extremities (whence they are termed four-handed),—a character which is only found elsewhere in the Opossums. Although some of the higher members of this group are capable of maintaining the erect position without difficulty for some time, even whilst walking, it is certainly not that which is natural to them. The posterior extremity,—being formed on the plan of a hand, for prehension rather than for direct support,—is destitute of the *heel* which is characteristic of Man: and although Apes can climb trees with facility, they cannot plant the foot firmly on the ground, and resist attempts to overthrow them; since the foot rests rather upon the outer side than upon its sole, and the narrowness of the pelvis is unfavourable to an equilibrium. There are many points, however, of striking resemblance to Man, in the details of the conformation of the Quadrumana, especially among the most elevated species; the order being distinguished by the same characters from most others. The structure of their alimentary canal differs extremely little from his. The eyes are directed forwards, when the trunk is erect; and the orbit is completely separated from the temporal fossæ by a bony partition. The mammæ are situated on the thorax; and the penis is pendent. Their coitus, however, is reverse, as in the lower Mammalia. The form of the brain in the higher species corresponds with that of Man in this remarkable character,—that it is divided into three lobes, of which the posterior is prolonged backwards so as to cover the cerebellum; this is not the case in the highest of other Mammalia.

Characteristics of Man.

62. We shall now review, somewhat in detail, the distinctive characters by which Man is separated from the animals that present the nearest approach to him in general structure and aspect. These may be advantageously classified according to their obvious purposes; and the first series which we shall notice, consists of those by which Man is peculiarly adapted to the erect attitude. On examining his cranium, we notice that the condyles, by which it is articulated with the spinal column, are so placed, that a perpendicular let fall from the centre of gravity of the head would nearly fall between them, so as to be within the base on which it rests. The foramen magnum is not placed in the centre of the base of the skull, but just behind it, in order to compensate for the greater specific gravity of the posterior part of the head, which is entirely filled with solid matter, whilst the anterior part contains many cavities. There is, indeed, a little over-compensation, which gives a slight preponderance to the front of the head, so that it drops forwards and downwards when all the muscles are relaxed. But the muscles which are attached to the back of the head are far larger and more numerous than those in front of the condyles; so that they are evidently intended to counteract this disposition; and we find, accordingly, that we can keep up the head for the whole day with so slight and involuntary an effort, that no fatigue is produced by it. Moreover, the surfaces of the condyles have a horizontal direction, when the head is upright; and thus the weight of the skull is laid vertically by them upon the top of the vertebral column. If these arrangements be compared with the position and direction of the occipital condyles in other Mammalia, it will be found that these are placed in the latter much nearer the back of the head, and that their plane is more oblique. Thus, whilst the foramen magnum is situated, in Man, just behind the centre of the base of the skull, it is found, in the Chimpanzee and Orang Outan to occupy the middle of the posterior third; and, as we descend through the scale of Mammalia, we observe that it gradually approaches the *back* of the skull, and at last comes nearly into the line of its longest diameter, as we see in the Horse. The obliquity of the

Fig. 5.



View of the base of skull of Man, compared with that of the Orang Outan.

condyles differs in a similar degree. In all Mammalia except Man, their plane is oblique; so that, even if the head were equally balanced upon them, the force of gravity would tend to carry it forwards and downwards. In Man, the angle which they make with the horizontal is very small; in the Orang Outan it is as much as 37°; and in the Horse, their plane is vertical, making the angle 90°. If, therefore, the natural posture of Man were horizontal, he would in this respect be circumstanced like the Horse; for the plane of his condyles, which is nearly horizontal in the erect position, would then be vertical; and the head, instead of being nearly balanced in the erect position, would hang at the end of the neck, so that its whole weight would have to be supported by some external and constantly acting power. But for this, there is neither in the skeleton, nor in the muscular system of Man, any adequate provision. In other Mammalia, the head is maintained in such a position, by a strong and thick ligament (the ligamentum nuchæ) which passes from the spines of the cervical and dorsal vertebræ to the most prominent part of the occiput; but of this in Man there is scarcely any trace. In the horizontal position, therefore, he would have the heaviest head, with the least power of supporting it.

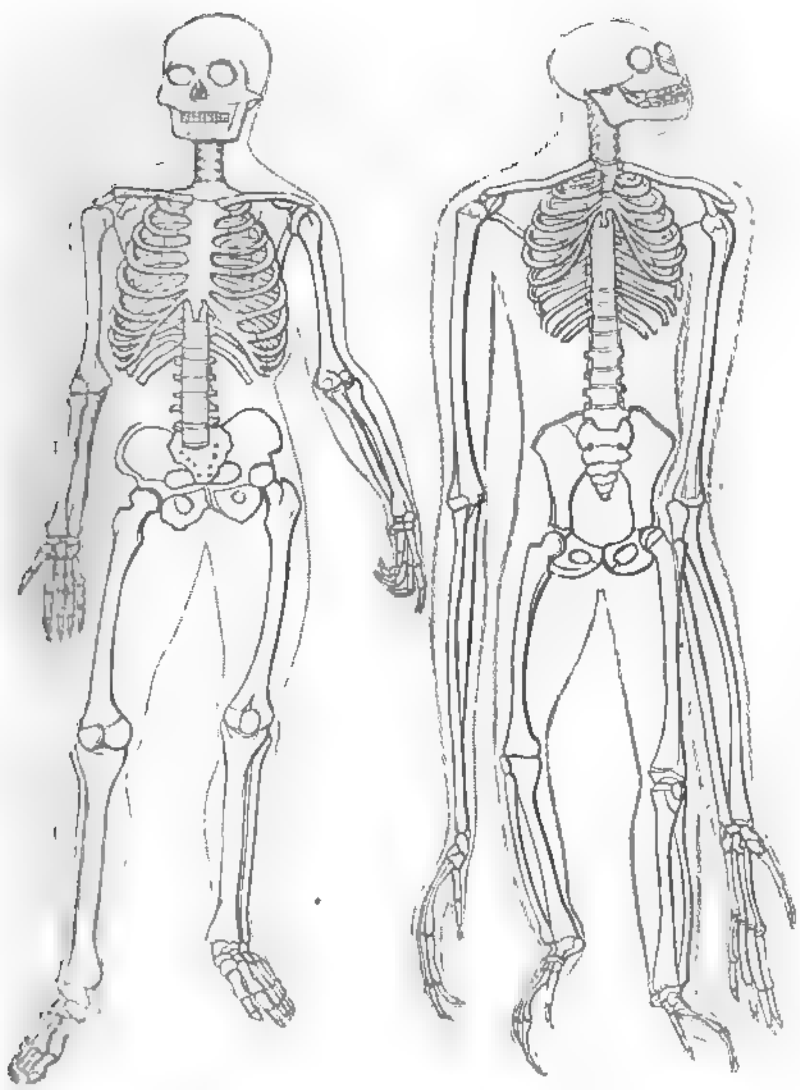
63. The position of the face immediately beneath the brain, so that its front is nearly in the same plane as the forehead, is peculiarly characteristic of Man; for the crania of the Chimpanzee and Orang, which approach nearest to that of Man, are entirely posterior to, and not above, the face. It should be remarked that, in the *young* Ape, there is a much greater resemblance to Man in this respect, than there is in the adult. For at the time of the second dentition, the muzzle of the Ape undergoes a great elongation, so that it projects much more beyond the forehead; this is seen in Fig. 5. The whole cast of the features is altered at the same time, so that it approaches much more to that of the lower Quadrumana, than would be supposed from observation of the young animal only.* This increased projection of the muzzle is an evidence of want of perfect adaptation to the erect posture; whilst the absence of it in Man shows that no other position is natural to him. Supposing that, with a head formed as at present, he were to move on all-fours, so that his face would be brought into the same plane with the ground, as painful an effort would be required to examine with the eyes an object placed in front of the body, as is now necessary to keep the eyes fixed on the zenith; the nose would be unable to perceive any other odours than those which proceeded from the earth or from the body itself; and the mouth could not touch the ground, without bringing the forehead and chin also into contact with it. The oblique position of the condyles in the Quadrumana enables them, without much difficulty, to adapt the inclination of their heads to the horizontal or to the erect position of the body; but the natural position, in the highest among them, is unquestionably one in which the spinal column is inclined, the body being partially thrown forwards, so as to rest upon the anterior extremities; and in this position, the face is directed forwards without any effort, owing to the mode in which the head is articulated with the spine.

64. The vertebral column in Man, though not absolutely straight, has its curves so arranged, that, when the body is in an erect posture, a vertical line from its summit would fall exactly on the centre of its base. It increases considerably in size in the lumbar region, so as to be altogether somewhat

* None but young specimens of the Chimpanzee and Orang Outan have ever been brought alive to this country; and they have never survived the period of their second dentition.

pyramidal in form. The lumbar portion in the Chimpanzee and Orang is not of the same proportional strength, and contains but four vertebræ instead of five. The processes for the attachment of the muscles of the back to this part are peculiarly large and strong in Man; and this arrangement is obviously adapted to overcome the tendency, which the weight of the viscera in front of the column would have, to draw it forwards and downwards. On the other hand, the spinous processes of the cervical and dorsal vertebræ, which are in other Mammalia large and strong, for the attachment of the ligamentum nuchæ to support the head, have in Man but little prominence, his head being nearly balanced on the top of the column. The base of the human vertebral column is placed on a sacrum of greater proportional breadth than that of any other animal; this sacrum is fixed between two widely expanded ilia; and the whole pelvis is thus peculiarly broad. In this manner, the femoral articulations are thrown very far apart, so as to give a wide basis of support; and by the oblique direction of the whole pelvis, the weight of the body is transmitted almost vertically from the top of the sacrum to the upper part of the thigh bones. The pelvis of every other species of the class is very differently constructed, as will be seen in the adjoining figure (6), in which the skeleton of the Orang is placed in proximity with that of Man. It is much longer and narrower, having a far smaller space between the iliac bones and the lowest ribs; the sacrum is lengthened and reduced in width; the alæ of the ilia are much less expanded; and the whole pelvis is brought nearly into a line with the vertebral column. The position of the human femur, in which it is most securely fixed in its deep acetabulum, is that which it has when supporting the body in the erect attitude. In the Chimpanzee and Orang, its analogous position is at an oblique angle to the long axis of the pelvis, with the body supported obliquely in front of it; in many Mammalia, as in the Elephant, it forms nearly a right angle; and in several others, as the Horse, Ox, &c., it forms an acute angle with the axis of the pelvis and spinal column.

65. The lower extremities of Man are remarkable for their length, which is proportionably greater than that which we find in any other Mammalia, except the Kangaroo tribe. It is evident that there could be no greater obstacle to progression in the horizontal posture, than this length of what would then be the hind legs. Either Man would be obliged to rest on his knees, with his thighs so bent towards the trunk, that the attempt to advance them would be inconvenient, his legs and feet being entirely useless; or he must elevate his trunk upon the extremities of his toes, throwing his head downwards, and exerting himself violently at every attempt to bring forward the thighs by a rotatory motion at the hip-joint. In either case, the only useful joint would be that at the hip; and the legs would be scarcely superior to wooden or other rigid supports. It is chiefly in the proportional length of the thigh, that Man differs from the semi-erect Apes. His arms, too, are shorter than theirs; so that his hands only reach the middle of the thighs, whilst in the Chimpanzee they hang on a level with the knees, and in the Orang they descend to the ancles. The Human femur is further distinguished by its form and position, as well as by its length. The obliquity and length of the neck still further increase the breadth of the hips, whilst they cause the lower extremities of these bones to be somewhat obliquely directed towards each other, so that the knees are brought more into the line of the axis of the body. This position is obviously of great use in walking, when the whole weight has to be alternately supported on each limb; for, if the knees had been further apart, the whole body must have been swung from side to side at each step, so as to bring the centre of



Comparative view of the Skeleton of Man and that of the Orang Outan

gravity over the top of each tibia; and, as a matter of fact, it is noticed that the walk of women, in whom the pelvis is broader and the knees more separated, is less steady than that of man. There is a very marked contrast between the knee-joint of Man, and that even of the highest Apes. In the former, the opposed extremities of the femur and the tibia are expanded, so as to present a very broad articulating surface; and the internal condyle of the femur is lengthened, so that the two are in the same horizontal plane, in the usual oblique position of the femur. In this manner, the whole weight of the body, in its erect posture, falls vertically on the top of the tibia, when the joint is in the firmest position in which it can be placed: and a comparison of the knee-joint of the Orang with that of Man, will make it at once evident, that the former is not intended to serve as more than a partial support. The weight of the body is transmitted through the tibia to the upper convex surface of the astragalus, and thence to the other bones of the foot. The Human foot is, in proportion to the size of the whole body, larger, broader, and stronger, than that of any other Mammal, save the Kangaroo. The sole of the foot is concave, so that the weight of the body falls on the summit of an arch, of which the os calcis and the metatarsal bones form the two points of support. This arched form of the foot, and the natural contact of the os calcis with the ground, are peculiar to Man alone. All the Apes have the os calcis small, straight, and more or less raised from the ground, which they touch, when standing erect, with the outer side only of the foot; whilst in animals more remote from man, the os calcis is brought still more into the line of the tibia; and the foot being more elongated and narrowed, the extremities of the toes only come in contact with the ground. Hence Man is the only species of Mammalia which can stand upon one leg.

66. If we look at the conformation of the upper extremity of Man, we observe similar proofs that it is not intended as an organ of support; it being destitute of all these adaptations; and having a conformation obviously designed for other purposes, which could not be possibly answered, if it were not completely relieved from the necessity of bearing the weight of the body. This peculiar conformation will be subsequently considered.

67. The other parts of the Human body concerned in locomotion are exactly adapted to the peculiar construction of the skeleton. The tibia is kept erect upon the foot by the very powerful muscles, which are attached to the heel and form the calf of the leg, a prominence observed in no other animal in nearly the same degree. The flexor longus pollicis pedis, which is attached in the Chimpanzee and Orang to the three middle toes, proceeds in Man exclusively to the great toe, on which the weight of the body is often supported. The extensors of the leg upon the thigh are much more powerful than the flexors,—an arrangement seen in no other animal. The glutæi, by which the pelvis is kept erect upon the thigh, are of far greater size than is elsewhere seen. The superior power of the muscles tending to draw the head and spine backwards, has been already referred to. In the general form of the trunk, there is a considerable difference between Man and most other Mammalia. His chest is large, but is flattened in front, and expanded laterally, so that its transverse diameter is greater than its antero-posterior;—a peculiarity in which only the most man-like monkeys partake. His sternum is short and broad, and there is a considerable distance between the lower ribs and the ilia, in consequence of the small number of ribs and the length of the lumbar portion of the vertebral column. The viscera in this space, which in the horizontal position would be but insufficiently held up by the abdominal muscles, are, in the erect attitude,

securely supported by the expanded pelvis. From all these facts it is an indisputable conclusion, that the erect attitude and biped progression are natural to Man; and we must regard as in great degree fabulous all those histories of supposed wild men, who, it has been said, were found in woods, dumb, hairy, and crawling on all-fours. The most elaborate investigation* of the structure of the anthropoid Apes, and the fullest acquaintance with their habits, concur in proving, that their movements are not easy or agile, unless they employ all their limbs for the support of their bodies.

68. The name Bimana is the most appropriate that could be found for an order constituted by the human species only; for Man alone is two-handed. "That," says Cuvier, "which constitutes the *hand*, properly so called, is the faculty of opposing the thumb to the other fingers, so as to seize the most minute objects,—a faculty which is carried to its highest degree of perfection in Man, in whom the whole anterior extremity is free, and can be employed in prehension." Some naturalists refuse the term *hand* to the extremities of the Monkey tribe, preferring to call them *graspers:* for it is certainly true that, although usually possessing an opposable thumb, they are destitute of the power of performing many of those actions which we regard as most characteristic of the hand. These actions are chiefly dependent on the size and power of the thumb, which is much more developed in Man than it is even in the highest Apes. The thumb of the Human hand can be brought into exact opposition to the extremities of all the fingers, whether singly or in combination; whilst in those Quadrumana which most nearly approach man, the thumb is so short and weak, and the fingers so long and slender, that their tips can scarcely be brought in opposition, and can never be opposed in near contact with each other, with any degree of force. Hence, although admirably adapted for clinging round bodies of a certain size, such as the small branches of trees, &c., the extremities of the Quadrumana can neither seize very minute objects with that precision, nor support large ones with that firmness, which are essential to the dexterous performance of a variety of operations, for which the hand of Man is admirably adapted. Hence the possession of "four hands" is not, as might be supposed, a character which raises the animals that possess it above two-handed Man; for none of these four hands are adapted to the same variety of actions of prehension of which his are capable, and all of them are in some degree required for support. In this respect their character approaches much nearer to that of the extremities of the lower Mammalia; and there are several among them in which, the opposable power of the thumb being deficient, there is no very marked distinction between the so-called hand, and the foot of some Carnivora. There is much truth, then, in Sir C. Bell's remark, that "We ought to define the hand as belonging exclusively to Man." There is in him, what we observe in none of the Mammalia that approach him in other respects, a complete distinction in the functional character of the anterior and posterior extremities; the former being adapted for prehension alone, and the latter for support alone. Thus each function is performed with a much higher degree of perfection, than it can be where two such opposite purposes have to be united. The arm of the Ape has as wide a range of motion as in Man, so far as its articulations are concerned; but it is only when the animal is in the erect attitude, that its arm can have free play. Thus the structure of the whole frame must conform to that of the hand, and must act with reference to it. But it can-

* See especially Mr. Owen's paper on the Chimpanzee and Orang Outan in the Zoological Transactions, Vol. i.

not be said with truth (as some have maintained) that Man owes his superiority to his hand alone; for without the directing mind, the hand would be comparatively valueless. His elevated position is due to his mind and its instruments conjointly; for if destitute of either, mankind would be speedily extinguished altogether, or reduced to a very subordinate kind of existence.

69. Thus, then, although the order Bimana cannot be separated from the order Quadrumana by any single obvious structural distinction, like that which characterizes the Cetacea or the Cheiroptera, it is really as far removed by the minuter, but not less important, modifications which have been detailed. A few other distinctive characters will now be noticed. With one exception (the fossil genus Anoplotherium, which is allied to the Tapir tribe) Man is distinguished from all other animals, by the equality in the length of all his teeth, and by the equally close approximation of them all in each jaw. Even the anthropoid Apes have the canine teeth longer than the others, and an interval in the line of teeth in each side of the jaw, to receive the canine teeth of the opposite jaw. This is more evident in the adult than in the young animal. The vertical position of the Human teeth, on which one of the most characteristic features of the human face—the prominent chin—depends, is also quite peculiar; and is intimately connected both with his erect attitude, and with the perfection of the hands, by which the food is divided and conveyed to the mouth. He has no occasion for that protrusion of the muzzle and lips, which, in animals that seize their food with the mouth only, is required to prevent the face from coming into general contact with it. The absence of any weapons of offence, and of direct means of defence, are remarkable characteristics of Man, and distinguish him from other animals. On those to whom Nature has denied weapons of attack, she has bestowed the means either of passive defence, of concealment, or of flight. Yet Man, by his superior reason, has not only been enabled to resist the attacks of other animals, but even to bring them under subjection to himself. His intellect can scarcely suggest the mechanism which his hands cannot frame; and he has devised and constructed arms more powerful than any other creature wields, and defences so secure as to defy the assaults of all but his fellow men. We find, on comparing the brain of Man with that of the lower Mammalia, that, as might have been anticipated, its proportional dimensions are much greater, and its structure more complex. The former part of this statement is easily verified by an examination of the cranium alone, comparing the size of its cavity with that of the face. The amount of the facial angle, taken after the manner of Camper, affords a tolerably correct indication of the relative sizes of these parts. In Man, the facial angle is, in the average of Europeans, 80°; in Negroes it is about 70°. In the adult Chimpanzee (which approaches in this respect nearest to Man) the facial angle is only 35°; and in the Orang it is no more than 30°. In other animals it is still less, except when it is increased by the prominence of large frontal sinuses, or by the comparative shortness of the jaws. In regard to the structure of the brain, we shall here only remark generally, that the encephalon of Man far exceeds that of the highest Quadrumana in the size of the cerebral hemispheres, in the complexity and development of its internal parts, and in the depth and number of its convolutions.

70. Man cannot be regarded as distinguished from other Mammalia, however, either by acuteness of sensibility, or by muscular power. His swiftness in running and agility in leaping are inferior to that of other animals of his size,—the full-grown Orang, for example. The smallness of

his face, compared with that of the cranium, shows that the portion of the nervous system distributed to the organs of sense is less developed in him than it is in most other animals; and the small proportional size of the ganglionic centres, with which these organs are immediately connected, is another indication of the same fact. Accordingly, he is surpassed by many in the acuteness of his sensibility to light, sound, &c.; but he stands alone in the power of *comparing* his sensations, and of drawing conclusions from them. Moreover, although none of his senses are very acute in his natural state, they are all moderately so, which is not the case in other animals; and they are capable (as is also his swiftness of foot) of being much improved by practice, especially when circumstances strongly call for their exercise. This power of adaptation to varieties in external conditions, which makes him to a great extent independent of them, is manifested in other features of his structure and economy. He is capable of sustaining the lowest as well as the highest extremes of temperature and of atmospheric pressure. In the former of these particulars, he is strikingly contrasted with the anthropoid Apes, such as the Chimpanzee, which is restricted to a few of the hottest parts of Africa, and the Orang Outan, which is only found in Borneo and Sumatra; these cannot be kept alive in temperate climates without the assistance of artificial heat; and even when this is afforded they speedily become diseased and die. His diet is naturally of a mixed kind; but he can support himself in health and strength on either animal or vegetable food exclusively. At the same time, it is by the demands which his peculiar condition makes upon the exercise of his ingenuity, that his mental powers are first called into active operation; and, when once aroused, their development has no assignable limit. The slow growth of Man, and the length of time during which he remains in a state of dependence upon his parents, have been already mentioned as peculiarities by which he is distinguished from all other animals. He is unable to seek his own food during at least the three first years of his life, and he does not attain to his full stature until he is more than twenty years of age. In proportion to his size, too, the whole sum of his life is greater than that of other Mammalia. The greatest age of the Horse, for example, which is an animal of much superior bulk, is between thirty and forty years. That of the Orang, which, when full grown, surpasses Man in stature, is about the same, so far as can be ascertained. The age to which the life of Man is frequently prolonged is well known to be above a hundred years; and instances of such longevity are to be found in all nations.

71. Still, however widely Man may be distinguished from other animals, by these and other peculiarities of his structure and economy, he is yet more distinguished by those mental endowments, and the habitudes of life and action thence resulting, which must be regarded as the essential characteristics of humanity. In the highest among brutes, the mere instinctive propensities (as already defined, § 28, 34,) are the frequent springs of action; and although the intelligent will is called into exercise to a certain extent, the character never rises beyond that of the child. In fact, the correspondence between the psychical endowments of the Chimpanzee, and those of the Human infant of between two and three years old, is very close. In Man, however, the instinctive propensities only manifest themselves strongly whilst the intellect is undeveloped; and nearly all the actions of adult life are performed under the direction of the intelligent will. From the intelligence of man results his improveability; and his improved condition impresses itself upon his organization. This capability of improvement in the bodily as well as the mental constitution of man, is the cause of the com-

forts now enjoyed by civilized races, and of the means which they possess of still further elevation. In the processes by which these are attained, we observe a remarkable difference between the character of Man and that of other animals. The arts of which these are capable, are limited and peculiar to each species; and there seems to be no *general* power of adapting these to any great variety of purposes, or of profiting by the experience of others. Where a particular adaptation of means to ends, of actions to circumstances, is made by an individual (as is frequently the case when some amount of intelligence or rationality exists), the rest do not seem to profit by it; so that there is no proof of any species or race among the lower animals ever making an advance towards an improvement or alteration in its condition. That modifications in structure and instincts may be induced by circumstances, in some of the most improveable species, such as the Dog, has been shown by abundant evidence; and these modifications, if connected with the original habits and instinct of the species, may be hereditarily transmitted. There is ample proof that the same is the case, in regard both to the corporeal structure and psychical endowments of Man. Under the influence of education, physical and mental, continued through successive generations, the capabilities of his whole nature, and especially those of his brain, are called out; so that the general character of the race is greatly improved. On the other hand, under the influence of a degraded condition, there is an equally certain retrogression; so that, to bring up the New Holland Savage or the African Bushman to the level of the European, would probably require centuries of civilization. One of the most important aids to the use and development of the human mind is the power of producing articulate sounds, or language, of which, as far as we know, Man is the only animal in possession. There is no doubt that many other species have certain powers of communication between individuals; but these are probably very limited, and of a kind very different from a verbal language.

72. Although, as we have stated, there is nothing in Man's present condition which removes him from the pale of the Animal kingdom, and although his reasoning powers differ rather in degree than in kind from those of the inferior animals, he seems distinguished by one innate tendency, to which we have no reason to suppose that any thing analogous elsewhere exists, and which we might term an instinct, were it not that this designation is generally applied to propensities of a much lower character. The tendency here referred to, is that which seems universal in Man, to believe in some unseen Existence. This may take various forms, but is never entirely absent from any race or nation, although (like other innate tendencies) it may be defective in individuals. Attempts have been made by some travellers to prove, that particular nations are destitute of it; but such assertions have been based only upon a limited acquaintance with their habits of thought, and with their outward observances. For there are probably none that do not possess the idea of some invisible Power external to themselves, whose favour they seek, and whose anger they deprecate, by sacrifice and other religious observances. It requires a higher mental cultivation than is always to be met with, to conceive of this Power as having a Spiritual existence; but wherever the idea of spirituality can be defined, it seems connected with it. The vulgar readiness to believe in demons, ghosts, &c., is only an irregular or depraved manifestation of the same tendency. Closely connected with it is the desire to share in this spiritual existence, which has been implanted by the Creator in the mind of Man, and which, developed as it is by the mental cultivation that is almost necessary for the formation of the idea, has been regarded by philosophers in all ages as one of the chief

natural arguments for the immortality of the soul. By this Immortal Soul, the existence of which is thus guessed by Man, but of whose presence within him he derives the strongest evidence from Revelation, Man is connected with beings of a higher order, amongst whom intelligence exists, unrestrained in its exercise by the imperfections of that corporeal mechanism by which it here operates; and to this state,—a state of more intimate communion of mind with mind, and of creatures with their Creator,—he is encouraged to aspire, as the reward of his improvement of the talents here committed to his charge.

CHAPTER II.

GENERAL VIEW OF THE FUNCTIONS.

73. The idea of *Life* or *Vital Action* obviously involves that of *change*. We do not consider any being as *alive*, which is not undergoing some continual alteration perceptible to the senses. This alteration may be so trifling in its amount, as not to be recognised but by frequent comparison. The slow-growing Lichen, that forms the grey or yellow spots upon old walls, or the Oyster that is lying motionless in its massive bed, may appear to perform no action; and yet a sufficiently prolonged knowledge of the former would show, that it is gradually though slowly extending itself, and that it is multiplying its race by a humble yet effectual process of fructification; whilst closer observation of the latter would enable us to perceive, that its surfaces are covered with cilia which are in continual vibration,—that food is being regularly taken into its stomach, undergoes digestion, and is converted into materials fit for the aliment of the body,—that a regular circulation of blood is maintained, by the action of a powerful heart,—that this circulation is subservient to the various processes of nutrition, secretion, and reproduction,—that in due time a number of young Oysters are produced, which swim forth from between the valves of the parent shell, and locate themselves elsewhere,—and lastly that, apathetic as the creature seems, it may be excited by some kinds of stimuli to a movement which seems to evince sensation, the closure of the shell being produced by any mechanical irritation of the contained animal, or even, it is said, when it lies undisturbed in its native haunts, by a shadow passing between it and the sun. Thus, then, *change* of some kind is essential to our idea of Life. It may be asked what is the condition of a seed, which remains unchanged during a period of many centuries, and at last vegetates, when placed in favourable circumstances, as if it had been ripened but the year before. The seed is not *alive*, but it is possessed of the property of *vitality*, or the power of performing vital actions, when aroused to them by the necessary stimuli,—such as warmth, moisture, oxygen, &c. Its condition resembles that of the human being in profound sleep; he is not then a feeling thinking man; but he is capable of feeling and thinking, when he is aroused from his slumber, and his mind is put into activity by the impressions of external objects.

74. The activity of a living being, then, being dependent upon two sets of conditions,—the organized structure which it possesses,—and the stimuli

to which this is exposed,—we can scarcely separate from our notion of an organized structure, that of the peculiar properties which it possesses; for we never see an organized structure remaining as such, unless it possess some degree of vitality. It may be said that, when an Animal or Plant is killed by a strong electric shock, its organization is unaffected, yet its vital properties are destroyed. Yet no proof of such an assertion, which is contrary to all analogy, has ever been afforded. In no other circumstances do we ever witness the departure of vitality, without some change of structure or of composition which can be made evident. In the ordinary *death* of an Animal, we may commonly trace the action of the morbific cause upon some particular organ, whose function is thereby either suspended or perverted; and the cessation of the whole train of actions necessarily results, if this organ be one of those essentially concerned in them. Thus, to take a not uncommon case, a patient with tubercular deposition nearly filling both lungs becomes the subject of an ulceration, which suddenly opens a passage from one of the bronchiæ to the pleural cavity on one side; death from this cause is frequently almost instantaneous, from the total incapacity of the other lung to maintain by itself those respiratory actions, which are necessary to the continuance of the circulation. Take again, for example, the influence of a narcotic poison; it occasions torpidity, first of the brain, and then of the medulla oblongata. So long as its action is confined to the brain, the general train of vital operations is no more disturbed, than it is in profound sleep; but as soon as it affects the medulla oblongata, the respiratory movements become paralyzed (from causes hereafter to be explained) and the circulation is soon brought to a stand; and every organ in the body speedily loses its characteristic properties, by the commencement of chemical changes in its composition. But, if the respiration be artificially sustained, the circulation will continue, and all the processes of nutrition, secretion, &c., to which it is subservient, will be performed with little interruption. Hence the cessation of the whole train, which would otherwise ensue, and the loss of vitality of the general structure, are due to the local change produced by the morbific cause; and the same may be traced, though not always so evidently, in a variety of other instances.

75. If we consider the actions exhibited by any living being, in which they are sufficiently complex and numerous to admit of being classified, we shall perceive that they may be associated into groups, termed *Functions*, of which every one, taken as a whole, has some positive and determinate purpose. Thus, one of the most universal of all the changes necessary to the existence of a living being, is the exposure of its nutritious fluid to the air, by the action of which upon it certain alterations are effected. For this aeration, simple as the change appears, many provisions are required. In the first place, there must be an aerating surface, consisting of a thin membrane, on the one side of which the blood may be spread out, whilst the air is in contact with the other. Then there must be a provision for continually renewing the blood which is brought to this surface, in order that the whole mass of fluid may be equally benefited by the process. And, in like manner, the stratum of air must also be renewed, as frequently as its constituents have undergone any essential change. We include, therefore, in speaking of the Function of Respiration, not only the actual aerating process, but also the various changes which are necessary to carry this into effect, and which have it for their obvious purpose.

76. On further examining and comparing these Functions, we find that they are themselves capable of some degree of classification. Indeed the distinction between the groups into which they may be arranged, is one of

essential importance in Animal Physiology. If we contemplate the history of the Life of a Plant, we perceive that it grows from a germ to a fabric of sometimes gigantic size,—generates a large quantity of organized structure, and many organic compounds, which form the products of secretion but do not undergo organization,—multiplies its species, by the production of germs similar to that from which it originated,—but that it performs all these complex operations, without (so far as we can perceive) either feeling or thinking, without consciousness or will. All the functions of which its Life is composed, are, therefore, grouped together under the general designation of Functions of *Organic* or *Vegetative* life; and they are subdivided into those concerned in the maintenance of the structure of the individual, which are termed those of *Nutrition*,—and those to which the *Reproduction* of the species is due. The functions of Nutrition may be thus generally described. The first part of the process is the *Absorption* of nutriment from without. This is carried by *Circulation* to the parts of the structure distant from those at which it was absorbed. At some of these parts, the absorbed fluid is brought into relation with the air, by which certain changes are effected in its constitution; these may be included under the general term *Aeration*, only a part of them being analogous to the Respiration of Animals. Having undergone these changes, and lost a considerable part of its superfluous water by the process of *Exhalation*, the alimentary fluid is prepared to be applied to its various purposes in the system; and, being carried through the fabric by the Circulation, it becomes subservient to the *Nutrition* and extension of the fabric, and to the formation of various products of *Secretion*. It also affords the means, to the organs of Reproduction, of the performance of their functions; since a new germ cannot be formed, any more than the parent structure can be extended, without organizable materials prepared by the foregoing processes, and supplied to the parts where active changes are going on.

77. On analyzing the operations which take place in the Animal body, we find that a large number of them are essentially the same in character, differing only in the particular conditions under which they are performed; and that we may, in fact, separate with great distinctness the Organic functions, which are directly concerned in the maintenance of the fabric, from those of Animal life, the chief purpose of which is entirely different. In commencing the survey of these, we must revert to what has been already said in regard to the nature of the food of Animals, and the means by which it is prepared to be applied to the wants of their system (§ 14). Not being received (in general at least) in any but the solid form, it has to be reduced to the fluid state, before it can be introduced by absorption into the system: this reduction is termed *Digestion;* and it must be regarded as not merely a process of mechanical separation or solution, but as one of chemical change, since it tends to the production of a compound, albumen, which might not have previously existed in the food. By a part of the same process, a certain degree of separation is effected, between the portion of the reduced aliment which is fit for absorption, and that which is not adapted to serve any purpose in the economy; and the latter, together with certain products of secretion, which it is equally desirable to get rid of completely, is at once cast out of the system. The alimentary fluid is, then, taken up by *Absorption*, through the lacteal vessels spread out upon the walls of the stomach and intestinal tube, precisely in the same manner as it is received into Plants through their roots distributed through the soil: hence the earth has been not unaptly designated as the common stomach of Plants, and Animals have been said to carry their soil about with them. The absorbed

fluid, having been introduced into the general current of the Circulation, is first carried to the Respiratory organs, where it is exposed to the action of the air; and it is then transmitted to the system, for the purposes of Nutrition, Secretion, and Reproduction. So far, then, the functions of the Animal system coincide with those of the Plant. The Organic functions of the former, however, have a purpose or object superadded to that which they perform in the latter, where their only end seems to be the production and maintenance of the individual fabric, and the continuance of the race. They are made subservient in Animals to those functions by which *they* are peculiarly characterized,—namely, *Sensation*, and *Voluntary Motion;* all the instruments of these operations being maintained, like the rest of the organic structure, in a state fit for activity, by the processes of Nutrition, which are performed on the same plan in them as in other parts.

78. The degree in which the operations of the *Mind* itself are *dependent* upon its material instruments, is a question which cannot be regarded as conclusively determined by scientific evidence alone; and it has little practical bearing on Physiological research. The doctrine usually regarded as having the best Scriptural basis,—that the mind has an existence altogether distinct from that of the body,—is attended with several difficulties, of which those arising out of the phenomena of Insanity are perhaps the most important. On the other hand, the opinion held by some, that mental phenomena are the mere results of material changes, appears to involve difficulties at least equal; amongst which may be noticed the consciousness of personal identity, preserved throughout the continual and rapid changes to which the Nervous structure is subject. The assertion, however, that psychical operations *cannot* be the result of material changes, is based on the assumption, that we know far more of the essential characters of both, than is admitted by the best Metaphysicians to be the case regarding either. This is one of the questions which scarcely comes within the boundaries of mere human knowledge. Neither hypothesis is inconsistent with the Revealed doctrine of the Immortality of the Soul; though the second could not be made to conform to it, without the additional supposition that some refined form of matter, on which psychical operations essentially depend, has also an eternal existence; and the upholders of this doctrine seek a confirmation of it in the expression "spiritual body," used by an authority which is all but supreme. The certainty of a future existence, in which all that is corruptible shall be done away, is the grand practical fact for the Christian; on the mode of it the philosopher may speculate; and, even though he may come to the conclusion that "Mind and Matter are logically distinct existences," yet he finds their operations so inextricably interwoven in the phenomena of Man's terrestrial life, that he cannot pursue either class of phenomena by itself alone. The Physiologist, therefore, will enter upon the inquiry with the best prospect of success, who is untrammelled by any preformed opinions, and who is ready to form his deductions from the facts presented to his notice.

79. That a very close relation may be traced between the variety and importance of the psychical phenomena of different classes of animals, and the complexity and size of their material instruments, all must admit; and it seems difficult, on the supposition of the completely distinct existence of Mind, to separate the phenomena to which organic changes are and must be essential, from such as do not require these for their production. For example, it is universally admitted that the mind cannot become cognizant of any impression made by an object external to it, except through the medium of a material change, commencing in the organ of sense, and pro-

pagated to the central sensorium; and yet of the absolute nature of this change we know nothing. Now the Sensation thus produced cannot give rise (as will be shown hereafter § 288) to a Perception,—the formation of an elementary notion of the nature of the object causing the impression,—without a series of changes in which Memory, Association, Judgment, &c. are involved. Memory seems clearly the result of the permanency of the material change effected by the sensation; for it is peculiarly liable to be affected by disorders or injuries of the brain, which do not impair that power of Comparison, and perception of Causation, by which the Reasoning faculty works upon the materials submitted to it. If Memory be thus connected with organic changes, the power of mental Conception, which is dependent upon the renewal of the state immediately produced by Sensation and Perception, is scarcely to be separated from them. Now it seems impossible to draw a distinct line between these operations, on the one hand, and the power of Imagination, which derives most or all of its materials from Conception, and the Reasoning Faculties, which are still more closely dependent upon impressions made from without, on the other. For the phenomena of Insanity are continually presenting to us instances of the disorder of these powers, without any corresponding disorder of the operations which intervene between them and the external world; and such disorder is often (perhaps uniformly) coincident with some morbid condition of the brain. In regard to the Moral Feelings and Emotions, again, it would seem equally impossible to separate these by a distinct line from the lower passions and instinctive propensities, which are so closely connected with material changes, as not to be distinguishable from them; and the daily experience, even of a person in ordinary health, reveals to him how strongly the emotional conditions of the mind are influenced by the state of the organic functions; and how powerfully, on the other hand, the latter are reacted on by the former. These, being phenomena which strictly form a part of the Life of Man, evidently belong to the domain of the Physiologist; and no speculative views can (or, at least, ought to) affect our reasoning from facts.

80. The operations of the Mind and its instruments, taken collectively, constitute what are known as the Functions of *Animal Life*. Those most obviously connected with the bodily fabric, are Sensation and spontaneous Motion; for these we find special instruments provided,—the organs of sense, and the muscular apparatus. Both these, with the nervous system itself, are composed, like other parts of the fabric, of organized structure, which does not differ essentially from that of the apparatus of Vegetative life, either in the mode of its first production, or in that in which its integrity is maintained, and its activity preserved. The conditions requisite for these objects will be presently discussed. But, although the functions of Animal life may be regarded as in themselves completely isolated from those of Organic life,—the latter merely supplying the conditions of the former, by keeping (so to speak) their instruments in good order,—yet there are certain links of connection between the two, which render the latter equally dependent on the former. Thus, in regard to the acquisition of food, the Animal has to make use of its senses, its psychical faculties, and its power of locomotion, to obtain that, which the Plant, from the different provision made for its support, can derive without any such assistance. Moreover, the propulsion of the food along the alimentary canal is effected by a series of operations, in which the Nervous and Muscular systems are involved at the two extremes, simple Muscular contractility being alone employed through the greater part of the intestinal canal. Thus, the change

in the condition required for the ingestion of food by Animals, has rendered necessary the introduction of an additional element in the apparatus, to which nothing comparable was to be found in Plants. Again, in the function of Respiration, as performed in the higher Animals, the Nervous and Muscular systems are alike involved; for the movements by which the air in the lungs is being continually renewed, are dependent upon the action of both; and those by which the blood is propelled through the respiratory organs, are chiefly occasioned by the contractility of a muscular organ,—the heart. But in regard to the simple contractility of muscular fibre, upon a stimulus directly applied to it, which is the agent in the movements of the heart and of the alimentary canal, it may be remarked that it does not differ in any essential degree from that which is witnessed in many Vegetables; and that it, therefore, strictly belongs to the functions of Organic life. And with respect to those concerned in the act of Respiration, as well as those which govern the two orifices of the alimentary tube, it will hereafter appear that they result, equally with the former, from the application of a stimulus; and that they may be performed without any consciousness on the part of the individual (though ordinarily accompanied by it):—the difference being, that in the former the stimulus is applied to the contractile part itself, whilst in the latter it is applied to an organ with which this is connected by nerves only. Now we have, even in Vegetables, instances of the propagation of an irritation from one part to another, so that a motion results in a part distant from that stimulated,—as in the case of the Sensitive Plant or Venus's Fly-trap: the only difference, therefore, between the movements of Animals which are thus closely connected with the maintenance of the organic functions, and those of Plants, consists in the medium through which they are performed,—this being in Animals the Nervous and Muscular apparatus, whilst in Plants it is only a peculiar modification of the ordinary structure.

81. From what has been said, then, it appears that all the functions of the Animal body are so completely bound up together, that none can be suspended without the cessation of the rest. The properties of all the tissues and organs are dependent upon their regular Nutrition by a due supply of perfectly elaborated blood; this cannot be effected unless the functions of Circulation, Respiration, and Secretion, be performed with regularity,—the first being necessary to convey the supply of nutritious fluid, and the two latter to separate it from its impurities. The Respiration cannot be maintained without the integrity of a certain part of the nervous system; and the due action of this, again, is dependent upon its regular nutrition. The materials necessary for the replacement of those continually separated from the blood, can only be derived by the Absorption of ingested aliment; and this cannot be accomplished without the preliminary process of Digestion. The introduction of food into the stomach, again, is dependent, like the actions of Respiration, upon the operations of the muscular apparatus and of a part of the nervous centres; and the previous acquirement of food necessarily involves the purely Animal powers. Now it will serve to show the distinction between these powers, and those which are merely subservient to Organic life, if we advert to the case, which is of no unfrequent occurrence, of a human being, deprived, by some morbid condition of the brain, of all the powers of Animal life,—Sensation, Thought, Volition, &c.; and yet capable of maintaining a vegetative existence,—all the organic functions going on as usual, the morbid condition not having affected that division of the nervous system which is concerned in the movements on which some of them depend. It is evident that we can assign no definite

limits to such a state, so long as the necessary food is placed within reach of the grasp of the muscles that will convey it into the stomach: as a matter of fact, however, it is seldom of long continuance; since the disordered state of the brain is sure to extend itself, sooner or later, to the rest of the nervous system. This condition may be experimentally imitated, however, by the removal of the brain, in many of the lower animals, whose bodies will sustain life for many months after such a mutilation; but this can only take place, when that food is conveyed by external agency, within the pharynx, which they would, if in their natural condition, have obtained for themselves. A similar experiment is sometimes made by Nature for the Physiologist, in the production of fœtuses, as well of the human as of other species, in which the brain is absent; these can breathe and suck and swallow, and perform all their organic functions; and there is no assignable limit to their existence, so long as they are duly supplied with food. Hence we may learn the exact nature of the dependence of the Organic functions upon those of purely Animal life; and we perceive that, though less immediate than it is upon the simply organic operations of the nervous and muscular systems, it is not less complete. On the other hand, the functions of Animal life are even more closely dependent upon the Nutritive actions, than are those of organic life in general; for many tissues will retain their several properties, and their power of growth and extension, for a much longer period after a general interruption of the circulation, than will the Nervous structure, which is, indeed, instantaneously affected by a cessation of the due supply of blood, or by the depravation of its quality.

82. It is of little consequence, then, with which group of functions we commence the detailed study of the phenomena, which in their totality make up the life of Man. In viewing him merely as one of the widely extended group of organized beings, it would be natural to commence with those phenomena which are common to all; and to make, therefore, the Organic functions the first object of our consideration. On the other hand, regarding Man as a being in some degree isolated from all these by his peculiar characteristics, it seems right to inquire into the latter in the first instance; more especially as, in a general view of his life, these occupy the most prominent place. It will be necessary, however, previously to entering upon these, to take a more detailed survey than we have hitherto done, of the vital operations performed by his several organs, and of their connections with each other. We shall commence with those of Vegetative Life.

Functions of Vegetative Life.

83. It is one of the most peculiar characteristics of organized structure, that its elements have a constant tendency (under ordinary circumstances at least) to separate into more simple combinations; and, although it has been ordinarily considered that their living state prevents such a change, and that they have no tendency to it except when dead, reason will hereafter be given for the belief that no such distinction exists. The maintenance of the vital properties of all organized structure, then, requires either that this structure should be completely secluded from air, moisture, warmth, and other agents which tend to its decomposition; or that it should be renewed as fast as it decays. Now the exclusion of these decomposing agents would prevent any vital actions from being called into operation; for they are the ordinary stimuli which are necessary to them. For instance, a seed which is buried so deep in the soil as to be excluded from the contact of air, and from the warmth of the sun, will not vegetate, although it may retain

its power of germinating when placed in more favourable circumstances. It is obviously necessary, then, that a provision should be made for removing from the organism, whilst in a state of activity, all those particles which are manifesting an incipient tendency to decay, and are thus losing their vital properties; and for replacing these by newly combined particles, which in their turn undergo the same process. Thus we find that, in the softest parts of the Animal framework, as in those of the Plant, there is much less permanency than there is in those harder and more solid portions, which often seem altogether to defy the lapse of time. Now it is in the former that the most active *vital* changes take place, those of the nervous system, for example; whilst of the latter the function is chiefly, if not entirely, that of giving *mechanical* support to the structure. The fact, which is easily proved, that the former organs are renewed many times, whilst the fabric of the latter is not once completely changed, shows a very interesting correspondence, between the degree in which the action of any organized structure is removed from or is similar to that of a mere inorganic substance, and the amount of tendency to decomposition which that structure exhibits; since this constant renewal can scarcely serve any other purpose, than that of making up for the effects of decay.

84. One of the most important purposes of the supply of aliment, therefore, which all living beings continually require, is the replacement of the portions of the fabric that are thus lost. The effects of the process of decay, when uncompensated by that of renovation, are remarkably seen in cases of starvation; for it is a very constant indication of this condition, that the body exhales a putrescent odour, even before death, and that it subsequently passes very rapidly into decomposition. This, it may be considered, is the reason why a constant supply of aliment is still required for the maintenance of every organic structure, though it may have arrived at its full growth; and it also affords one source of explanation of the fact, that old people require less food than adults, since their tissues are more consolidated, and thus become at the same time unable to perform their usual actions with their pristine energy, whilst their tendency to decomposition is less. In the growing state, however, an additional important source of demand for food obviously exists, in the extension which the tissues themselves are constantly receiving; yet this, perhaps, does not make so great a difference, as it appears to do, in the supply which is requisite. For if the *addition* which is made by growth to the body in any given time, be compared with the amount of *exchange* which has taken place in the same time,—the latter being judged of by the quantity of matter excreted from the lungs, liver, kidneys, skin, &c.,—it will be found to bear but a very small proportion to it, except during fœtal life, when the growth is very rapid, and a large proportion of the effete particles are brought to the maternal blood, to be excreted from it. The real cause of the increased demand for nutriment during the early part of life is rather this,—that the tissues are far from having acquired that firmness and consolidation which they gain at adult age; and that they are, therefore, more prone to decomposition, at the same time that their vital activity is greater, as is well known to be the case. The feeling of hunger or desire for food originates, we shall hereafter find reason to believe, not so much in the stomach itself as in the system at large; of whose condition, in regard to the requirement of an increased supply of aliment, it may during the state of health be considered as a pretty faithful index. The same may be said of thirst. The feeling of hunger, then, is the stimulus to the mental operations which have for their object the acquisition of food, whether these be of a voluntary or of a purely in-

stinctive kind; in Man they are obviously the former, during all but infant life.

85. The food received into the mouth, and prepared there by the acts of mastication and insalivation (the movements concerned in which are depedent upon the brain, and can only be performed when it is in a condition of some activity), is brought by them within reach of the pharyngeal muscles, whose contraction cannot be effected by the will, but is purely instinctive,—resulting merely from the impression made upon the fauces by the contact of the substance swallowed, which impression is conveyed to the medulla oblongata and reflected back to the muscle. By these it is propelled down the œsophagus; and, after their action has ceased, it is taken up (as it were) by the muscular coat of the œsophagus itself, and conveyed into the stomach. How far the movements of the lower parts of the œsophagus and of the stomach are in Man dependent upon reflex action, is uncertain; the facts which have been ascertained on this point by experiment on animals will be detailed in their proper place. In the stomach, the food is subjected to the action of the gastric secretion; the chemical action of which, aided by the constantly elevated temperature of the interior of the body, and by the continual agitation effected by the contractions of the parietes of the organ, effects a more or less complete solution of it. Reason will hereafter appear for the belief that, up to this point, no action peculiarly *vital* is immediately concerned in the reduction of the food; and that, if the physical conditions of the process could be exactly imitated out of the body, the result would be precisely the same. The mixture of the biliary and pancreatic secretions with the *chyme* thus produced, occasions a separation of its elements into those adapted for nutrition, and those of which the character is excrementitious; and this separation can scarcely be regarded in any other light than as a chemical precipitation. The nutritious portion is then taken up by the Absorbent vessels, or Lacteals, which are distributed on the walls of the alimentary canal; whilst the remainder is propelled along the intestinal tube by the simple contractility of its walls, undergoing at the same time some further change, by which the nutritive materials are still more completely extracted from it. And at last, the excrementitious matter, consisting not only of a portion of the food taken into the stomach, but also of part of the secretion of the liver and of that of the mucous surface of the intestines, is voided from the opposite extremity of the canal, by a muscular exertion, which is partly reflex, like that of deglutition, but is partly voluntary; especially (as it would appear) in Man.

86. The nutritious fluid taken into the absorbents, which now receives the name of Chyle, is propelled through them by the contractility of their walls, aided in part, perhaps, by a *vis a tergo* derived from the force of the absorption itself. This force exists to a considerable extent in the roots of Plants, and evidently depends on the physical law of Endosmose; but it is quite uncertain how far the process of Absorption in Animals depends on the same principles. With the reception of the nutritious fluid into the absorbent vessels, commences its real preparation for organization. Up to that period, it cannot be said to be in any degree *vitalized;* the changes which it has undergone being only of a chemical and physical nature, and such as merely *prepare* it for subsequent assimilation. But in its passage through the long and tortuous system of absorbent vessels and glands, it undergoes changes which, with little chemical difference, manifest themselves by a decided alteration in its properties; so that the chyle of the thoracic duct is evidently a very different fluid from the chyle of the lacteals, approaching much nearer to blood in its general characters. These charac-

ters are such as indicate that the process of organization and vitalization has commenced; as may be known alike from the microscopic appearance of the fluid, and from the actions it performs when removed from the body. It is then conveyed into the Sanguiferous system of vessels, and flows directly to the heart, by which it is transmitted, with the mass of the blood, to the lungs. It there has the opportunity of excreting its superfluous carbonic acid, and of absorbing oxygen; and probably acquires gradually the properties by which the blood previously formed is distinguished, and thus becomes the *pabulum vitæ* for the whole system.

87. The Circulation of the Blood through the tissues and organs which it is destined to support, is a process evidently necessary for the conveyance to them of the nutritious materials which are provided for the repair of their waste, and for the removal of those elements of their fabric which are in a state of incipient decomposition. In the lowest classes of organized beings, every portion of the structure is in direct relation with its nutritive materials; it can absorb for itself that which is required, and it can readily part with that of which it is desirable to get rid. Hence in such, no general circulation is necessary. In Man, on the other hand, the digestive cavity occupies so small a portion of the body, that the organs at a distance from it have no other means, than their vascular communication affords, of participating in the results of its operations; and it is moreover necessary, that they should be continually furnished with the organizable materials, of which the occasional operation of the digestive process would otherwise afford only an intermitting supply. This is especially the case, as already mentioned, with the nervous system, which is so predominant a feature in the constitution of Man; and we accordingly find both objects provided for, in the formation of a large quantity of a semi-organized product, which contains within itself the materials of all the tissues, and is constantly being carried into relation with them. Blood has been not unaptly termed *chair coulante*, or liquid flesh; and although it has been heretofore much questioned, whether it could be regarded as either organized or endowed with vital properties, there will hereafter appear to be sufficient reason for admitting, that this is the case to a very considerable extent. The propulsion of the blood through the large trunks, which subsequently divide into capillary vessels, is due to the contractions of a hollow muscular organ, the heart; but these, like the peristaltic movements of the alimentary canal, are quite independent of (though frequently influenced by) the agency of the nervous system; and are therefore to be referred to the class of organic movements, such as occur in Vegetables.

88. Upon the circulation of the blood through all parts of the fabric, depends in the first place the *Nutrition* of the tissues. Upon this subject, formerly involved in the greatest obscurity, much light has recently been thrown. In the lowest classes of Plants and Animals, the whole or the greatest part of the fabric is composed of vesicles or cells aggregated together, each of which has a certain degree of independent vitality, and can live to a great extent by itself alone, if duly supplied with nutriment. These cells differ but little from each other in structure and endowment; and the whole mass approaches far more nearly, therefore, to the homogeneous character of inorganic bodies, than does that of beings more elevated in the scale. This is precisely the condition of the embryonic structure of the highest Animals at an early period of their existence. Now in such fabrics, there is no distinct vascular system. Every cell absorbs, either from the surrounding nutritious materials with which it may be itself in contact, or from other cells in nearer proximity to these, the aliment it

requires for its own growth and reproduction; and performs all its vital processes with little direct influence from any general controlling power. The extension of the individual structure is partly effected by the enlargement of its original vesicles; but principally by the generation of new ones within these; and the latter in their turn go through the same processes. In the higher Plants, however, we find a greater variety of tissues, which all take their origin, however, in cells. The straight tubes, for instance, which convey the sap from the roots to the leaves, were evidently at first a line of large cells, laid end to end, the partitions between which have broken down: and the network of anastomosing vessels, by which the descending or nutritious sap is conveyed through the tissues, may be traced to a corresponding origin. The circulation of the sap which thus regularly takes place, causes these Plants to receive the name of *Vascular*, whilst the others are designated as *Cellular;* but still it is to be remembered that the great bulk of the structure in the former, like the whole of the latter, is composed of vesicular tissue; and that the central part of the *islands*, so to speak, which are composed of this, in the interstices of the vascular network, cannot be nourished in any other way, than by absorption from the cells which surround them. In the higher Animals, the variety of tissues which present themselves in the adult structure, all formed by a metamorphosis from the original vesicles of the embryo, is very great, but these are all nourished, in a more or less energetic manner, by the blood conveyed to them in the network of minute vessels which traverses them. Still between the reticulations of these vessels, there must necessarily be islands of solid tissue (as seen in Fig. 44), of no inconsiderable size; and the central portions of these must derive their nourishment from the surrounding cells, exactly as in the humblest Cellular Plants. Moreover there are some tissues in which, in the healthy state at least, no very minute distribution of blood-vessels can be ascertained to exist; and in these the cellular nutrition must go on to a considerable extent. The decay and renewal of such tissues, however, is by no means rapid; and it is only in such as require little change from time to time, and whose actions are of a physical rather than of a vital character (such, for instance, as Cartilage), that this mode of nutrition is sufficient.

89. In the nutrition of the tissues which are already completely formed, it seems probable that the fluid portion of the blood performs the chief part. The red corpuscles serve the important purpose of conveying oxygen from the lungs into the interior of the system, and of carrying away carbonic acid from the tissues; since it is evidently in them, that the chief chemical changes effected by Respiration are produced; and the heat regularly maintained in any class of animals bears a very close proportion to the quantity of red particles in their blood.

[Until a comparatively recent period, nothing has been known of the phenomena of *cell-life* in animals. Although many isolated facts had been ascertained by Purkinje, Valentin, Henle, Müller, Wagner, Turpin, and others, in regard to the existence of nucleated cells in the solids and fluids of the body, the production of these cells from pre-existent nuclei, and the development of new cells within those of a preceding generation, it was Schwann who first gave expression to the important generalization, that nucleated cells are the basis of *all* animal as well as vegetable structures; a doctrine more fruitful, perhaps, in novel results and widely-extended applications, than any other in modern physiology. For whilst some of the followers of Schwann, in the same line of inquiry, have shown that certain

limitations are necessary, a few of the tissues being produced more directly, by the simple consolidation of the fluid plasma into fibrillæ and membranous lamellæ, and some (as would appear from Henle's observations) being formed by the coalescence of the elements of cells, whose development into cells has been arrested; other observers have given an extension to Schwann's doctrines that he could not have himself anticipated. For not only does it now appear that nearly all the animal tissues, however great the alterations they may have undergone in structure and properties, have their immediate origin in cells; but that *in animals as in plants, all the changes in which organic life essentially consists are performed by cells, scarcely distinguishable from each other by any well-marked characters.*

[The author is not aware that this proposition has been yet stated in so general a form. In fact, many of the data upon which it is founded are but of very recent discovery. It may be necessary to explain briefly the meaning and application of this statement before proceeding to the demonstration of it. The purely *animal* functions, those of the nervous and muscular systems, are not included in it; nor are those of a merely physical character, such as the movement of fluids through canals, or the resistance and support afforded by the solid and elastic tissues. These last, as in vegetables, may be regarded as *addenda* for the purpose of supplying the conditions necessary for those really vital operations in which organic life essentially consists. We know of no animal so simple as the lowest cryptogamic plant; but there is reason to believe that there are many in which no vessels exist, their tissue being everywhere in near contact with the nutrient fluid, and absorbing directly from it; and it is certain that there are many in which a few scattered muscular fibres and nervous filaments constitute the only departure from the general type of *cellular** tissué. Here, then, there is no difficulty in understanding that all the functions of organic life, absorption, assimilation, nutrition, respiration, secretion, and reproduction, must be performed by cells. Again, in the early condition of the embryo, which is at first nothing more than a mass of cells, precisely the same holds good. For some time, its life is entirely vegetative; it absorbs its nutriment by cells spread over the yolk; and this nutriment is at first applied solely to the development of new cells, some of which gradually undergo metamorphosis into other tissues. But the same will be found true of this function in the adult state of the highest animal: for nutritive absorption is in it also performed by cells, which appear destined to this function alone. In like manner it will appear that another set of cells have for their office the assimilation of the nutriment, that is, the preparation of it for entering into the composition of the living organized body. Further, it seems certain that the first development of nearly all the tissues takes place from cells, which are produced at the expense of this assimilated nutriment. Again, the separation from the circulating fluid of these products which are to be cast off from it, is also accomplished by cells. With regard to the simple exhalation of fluid, it may be remarked that this, like imbibition, is a physical function, dependent upon the permeability of membrane; and that the vital action of cells is therefore not necessary for it. The same may perhaps be said of respiration; but we shall find that in this the action of cells is concerned. Lastly in regard to reproduction, it appears that the essential part of this process

* The term *cellular* tissue is here applied to the structure properly deserving that name, from its being composed of distinct cells or vesicles, like the parenchyma of plants. That which has been ordinarily termed cellular tissue in animals is much better named fibro-cellular [or areolar] tissue.

consists, among animals as among plants, of the multiplication of cells under peculiar conditions.]

90. The history of the changes by which one group of cells is transformed into bone, another into cartilage, another into nerve, another into muscle,—and so on,—is extremely interesting, and will be given hereafter in as much detail as the limits of this work permit. Of the reason why this variety of products should spring up, when the cells in which they all originate appear to be so exactly alike, and have themselves a common origin, no account can be given; and this is one of the most curious problems that at present offers itself for investigation. The important discoveries, which are here briefly summed up, are not confined to healthy structures; for it has been ascertained that diseased growths have a similar origin and mode of extension; and that the *malignant* character, assigned to Cancer, Fungus Hæmatodes, and other such productions, is to be traced to the fact, that they are composed of cells which undergo little metamorphosis, and retain their reproductive power; so that from a single cell, as from that of a Vegetable Fungus, a large structure may rapidly spring up, the removal of which is by no means attended with any certainty that it will not speedily re-appear from some germs left in the system.

91. The independent character of the cells in which all organized tissues originate, might be of itself a satisfactory proof that, in Animals, as in Plants, the actions of Nutrition are performed by the powers with which they are individually endowed; and that, whatever influence the nervous system may have upon them, they are not in any way essentially dependent upon it. Moreover, there is an evident improbability in the idea, "that any one of the solid textures of the living body should have for its office, to give to any other the power of taking on any vital actions;" and the improbability becomes an impossibility when the fact is made known, that no formation of nervous matter takes place in the embryonic structure, until the processes of organic life have been for some time in active operation. The influence which the Nervous System is known to have upon the Function of Nutrition, is probably exerted rather through the medium of its power of regulating the diameter of the arteries and capillaries, by which it controls in some degree the afflux of blood, and of affecting those preliminary actions on which the quantity and quality of the nutritious fluid depend, than in any more direct manner. At any rate, it may be safely asserted that no such proof of its more direct influence, as is required to counterbalance the manifest improbability which has been shown to attend it, has yet been given,—all the facts which have been adduced in support of this hypothesis being equally explicable on the other, which, being in itself more probable, ought to be preferred.

92. The renewal which the various tissues of the body are continually undergoing, has for its chief object the counteraction of the decay into which they would otherwise speedily pass; and it is obviously required that a means should be provided for conveying away the waste, as well as for supplying the new material. This is partly effected by the venous circulation, which takes up a large part of the products of incipient decomposition, and conveys them to organs where they may be separated and cast forth from the body. The first product of the decay of all organized structures, is carbonic acid; and this is the one which is most constantly and rapidly accumulating in the system, and the retention of which, therefore, within the body, is the most injurious. Accordingly we find two large organs adapted to remove it, and to both these venous blood passes, before it is again

sent through the system. The function of the Lungs is so important in warm-blooded animals, that a special heart is provided for propelling the blood through them, in addition to that possessed by most of the lower animals, the function of which is the propulsion of the blood through the system. In these organs the blood is subjected to the influence of the atmosphere, by which the carbonic acid with which it was charged, is removed and replaced by oxygen; the introduction of this element into the blood seems necessary alike to maintain its general vivifying powers, and to remove the carbon set free in the tissues, by converting it into carbonic acid. This corresponds with the general fact, that carbonic acid cannot be formed by decomposition, at least to any large amount, except when the decaying substance has oxygen within its reach. The continual formation of carbonic acid in the tissues appears to have a most important purpose in the vital economy,—that of keeping up its temperature to a fixed standard; for the union of carbon and oxygen in this situation may be compared to a process of slow combustion, and it is well known that, the more energetic this is, the higher is the temperature. Thus in Birds, whose nutrition is so active, and whose respiration is so energetic, the temperature is constantly maintained at a point higher than that which other animals ever attain, in the healthy state at least; whilst in Reptiles, which present a condition exactly the reverse of this, the temperature is scarcely above that of the surrounding medium. The function of the Liver is, like that of the lungs, two-fold:—it separates from the blood a large quantity of the superfluous carbon which it acquires by circulating through the tissues;—and it combines that carbon with other elements, into a secretion, which, as we have seen, is of great importance in the digestive process. The hepatic circulation, however, is not kept up by a distinct impelling organ; but the venous blood from the abdominal viscera (and in the lower Vertebrata that from the posterior part of the body) passes through the Liver on its return to the heart.

93. All animal substances have a tendency, during their decomposition, to throw off nitrogen, as well as carbonic acid; and this nitrogen may take either the form of cyanogen, by going off in combination with carbon, or of ammonia, by uniting at the time of its liberation with hydrogen. The chief function of the kidneys is evidently to separate the azotized products of decay from the circulating fluid; for the secretion which is characteristic of them,—namely *urea*,—contains a larger proportion of nitrogen than is found in any other organic compound; it is identical in its chemical nature with cyanide of ammonia, and may be considered as the result of the union of these two products of animal decomposition. The action of the kidneys is equally essential to the continued performance of the other vital functions, with that of the lungs and liver; since death invariably follows its suspension, unless some other means be provided by Nature (as occasionally happens), for the separation of its characteristic excretion from the circulating blood. But death does not so speedily ensue, when the functional action of the liver and the kidneys is suspended, as when that of the lungs is checked; and for this obvious reason,—that only a part of the whole current of blood flows through the former organs, and that, although a disturbance of the usual course of the circulation must ensue from a stagnation of the flow through them, it is not from this cause brought to a stand; whilst, in the case of the lungs, the fact that the whole of the blood is sent to them, before it can be again impelled through the body, necessitates the immediate cessation of the systemic circulation, when the pulmonary has been

checked. In the class of Reptiles, the lungs are on somewhat of the same footing with the liver and kidneys in warm-blooded Vertebrata,—that is, only a part of the blood which has returned from the system is transmitted through them, before being again propelled through the body; and, accordingly, the interruption of the pulmonary circulation does not in them involve immediate death. Indeed in the naked-skinned Batrachia, the cutaneous surface has enough respiratory power to effect that degree of aeration of the blood, which is necessary whilst the temperature is low, and the vital actions thereby diminished in energy.

94. There seems reason to believe, however, that, of the products of decomposition which are set free in the various tissues and organs of the body, only a part is destined to be immediately excreted; and that it is this part which is taken up by the Veins, and conveyed, by the general vascular apparatus, to the several glands which are to separate it. The remainder, consisting of substances which are fit to be reassimilated, appears to be taken up by a distinct system of vessels termed *Lymphatics*, which may be considered as an extension of the Lacteal system through the fabric at large. There is good reason to believe that the special function of the Lymphatics is, like that of the Lacteals, to minister to *Nutritive* Absorption, (although other substances *may* find their way into them, by the mere physical process of imbibition); the latter being especially destined to take up assimilable matter from the digestive cavity, whilst the former absorb the products of the secondary digestion which is continually going on in every part of the body. (See §§ 464–467). Of these, however, a portion may still be destined to immediate excretion.

95. The various Secretions which have not already been adverted to, appear for the most part to have for their object the performance of some special function *in* the system, rather than the conveyance *out* of it of any substances which it would be injurious to retain. This is the case, for example, in regard to the secretion of the Lachrymal, Salivary, and Mammary Glands, as well as with that of the Mucous and Serous Membranes. The Excretion of fluid from the cutaneous surface, however, appears to answer two important purposes,—the removal from the body of a portion of its superfluous fluid,—and the regulation of its temperature. Just as, by the action of the lungs, the conditions are supplied, by which the temperature of the body is kept up to a certain standard, so, by that of the Skin, it is prevented from rising too high; for by the continual excretion from its surface, of fluid which has to be carried off by evaporation, a degree of cold is generated, which keeps the calorific processes in check; and this excretion is augmented in proportion to the elevation of the external temperature, which seems, in fact, the direct stimulus to the process.

96. There is no sufficient reason to believe, that the Nervous System has any more direct influence on the processes of Secretion, than it has been stated to have on that of Nutrition. That almost every secretion in the body is affected by states of mind which must operate through it, daily experience teaches; but the very remarkable degree of control which the nervous system possesses over the circulation, is quite sufficient to explain any of these effects, whether they be local or general. The flow of the secreted fluids through their efferent ducts appears to be principally caused by the proper contractility of these, which (like that of the heart and alimentary canal) is directly stimulated by the contact of their contents; but there is also evidence that this contractility may be affected (as it is in those two instances) by the nervous system; and thus we have an additional

means of influence, by which the nervous system can affect these processes, since its power is probably not confined to the large ducts, but extends to their ultimate ramifications. Where, as happens in the case of the urinary excretion, there is a reservoir into which it is received as fast as it is formed, for the purpose of preventing the inconvenience which its constant passage from the body would otherwise occasion,—the power of emptying this reservoir is usually placed in some degree under the dominion of the will, although chiefly governed by reflex action. It is obvious that such a provision is by no means essential to the function; and that it has for its object the adaptation, merely, of that function, to the conditions of Animal existence.

97. Thus we see that, when we enter, as it were, into the *penetralia* of the Animal system, and study those processes of which the Life of the material fabric essentially consists, we find them performed under conditions essentially the same as those which obtain in Plants; and we observe that the operations of the Nervous System have none but an indirect influence or control over them. It is, therefore, quite philosophical to distinguish these Organic Functions, or phenomena of Vegetative Life, from those concerned in the Life of Relation, or Animal life. The distinction is, indeed, of great practical importance, and lies at the foundation of all Physiological Science; yet it is seldom accurately made, and a very confused notion on the subject is generally prevalent. It is commonly said, for example, that the function of Respiration is the connecting link between the two:—the fact being, however, that the *true* process of Respiration is no more a function of Animal Life than is any ordinary process of secretion; but that, in order to secure that constant interchange of air, which is necessary to its performance, the assistance of the nervous and muscular systems is called in, though not in a manner which necessarily involves either *consciousness* or *will*.

98. The process of Reproduction, like that of Nutrition, has been until recently involved in great obscurity; and although it cannot be said to be yet fully elucidated, it has been brought, by late investigations, far more within our comprehension, than was formerly deemed possible. The close connection between the Reproductive and Nutritive operations, both as regards their respective characters, and their dependence upon one another, has long been recognised; and it is now rendered still more evident. Nutrition has been not unaptly designated "a perpetual reproduction;" and the expression is strictly correct. In the fully-formed organism, the supply of alimentary material to every part of the fabric enables it to produce a tissue resembling itself; thus we only find true bone produced in continuity with bone, nerve with nerve, muscle with muscle, and so on. Thus it would appear that, when a group of cells has once taken on a particular *kind* of development, it continues to reproduce itself on the same plan. But in the Reproductive process it is different. A single cell is generated by certain preliminary actions,—from which single cell all those which subsequently compose the embryonic structures take their origin; and it is not until a later period, that any distinction of parts can be traced in the mass of vesicles which spring from it. Hence the essential character of the process of Reproduction consists in the formation of a cell, which can give origin to others, from which again others spring,—and in the capability of these last to undergo *several* kinds of transformation, so as ultimately to produce a fabric in which the number of different parts is equal to that of the functions to be performed, every separate part having a purpose distinct from that of the rest. Such a fabric is considered as a very *heterogeneous* one, and is

eminently distinguished from those homogeneous organisms, in which every part is but a repetition of the rest. Of all Animals man has, as already shown, the greatest variety of endowments,—the greatest number of distinct organs; and yet Man, in common with the simplest Animal or Plant, takes his origin in a single cell. It is in the almost homogeneous fabrics of the Cellular Plants, that we find the closest connection between the function of Nutrition and that of Reproduction; for every one of the vesicles which compose their fabric is endowed with the power of generating others similar to itself; and these may either extend the parent structure, or separate into new and distinct organisms. Hence it is scarcely possible to draw a line, in these cases, between the Nutrition of the individual and the Reproduction of the species.

99. But, it will be inquired, how and where in the Human body (and in the higher Animals in general) is this embryonic vesicle produced, and what are the relative offices of the two sexes in its formation? This is a question which must still be answered with some degree of doubt; and yet observed phenomena, if explained by the aid of analogy, seem to lead to a very direct conclusion. The embryonic vesicle itself, like other cells, must arise from a germ; and reasons will be hereafter given for the belief, that the germ is supplied by the male parent, and that the female supplies only the materials for its development. Here, as in the Nutritive processes, we find that the operations immediately concerned in this function,—namely, the act of fecundation, and the development of the ovum,—are not directly influenced in any way by the nervous system; and that the functions of Animal Life are called into play, only in the preliminary and concluding steps of the process. In many of the lower Animals, there is no sexual congress, even where the concurrence of two sets of organs (as in the Phanerogamic Plants) is necessary for the process; the ova are liberated by one, and the spermatozoa by the other; and the accidental meeting of the two produces the desired result. In many Animals higher in the scale, the impulse which brings the sexes together is of a purely instinctive kind. But in Man, it is of a very compound nature. The instinctive propensity, unless unduly strong, is controlled and guided by the will, and serves (like the feelings of hunger and thirst) as a stimulus to the reasoning processes, by which the means of gratifying it are obtained; and a moral sentiment or affection of a much higher kind is closely connected with it, which acts as an additional incitement. Those movements, however, which are most closely connected with the essential part of the process, are, like those of deglutition, respiration, &c., simply reflex and involuntary in their character; and thus we have another proof of the constancy of the principle, that, where the action of the apparatus of Animal Life is brought into near connection with the Organic functions, it is not such as requires the operation of the purely animal powers. Thus, then, as it has been lucidly remarked, "the Nervous System lives and grows within an Animal, as a parasitic Plant does in a Vegetable; with its life and growth, certain sensations and mental acts, varying in the different classes of Animals, are connected by nature in a manner altogether inscrutable to man; but the objects of the existence of Animals require that these mental acts should exert a powerful controlling influence over all the textures and organs of which they are composed."

Functions of Animal Life.

100. The existence of *consciousness*, by which the individual (*le moi*, in the language of French physiologists) becomes *sensible* of impressions made

upon its bodily structure,—and the power of *spontaneously* exciting contractions in its tissues, by which evident motions are produced,—have been already stated to be the peculiar attributes of the beings composing the Animal kingdom. The evident motions exhibited by some Plants, cannot be regarded as indicating the existence of any psychical endowments in the beings included in the Vegetable kingdom; for they are usually to be referred without difficulty to the action, either direct or indirect, of an external stimulus, upon a contractile tissue; and even where no such action *evidently* takes place, there is good reason to suppose its existence. To refer, therefore, the movements of Vegetables to a nervous system, of which no traces can be fonhd,—still more to suppose them endowed with consciousness and will, as some have done, is to violate most grossly a well-known rule in philosophy, which cannot be too steadily kept in view in prosecuting physiological inquiries—*non fingere hypotheses.*

101. There are in Animals, however, many movements which are equally dependent upon direct stimuli for their production. Such are (as we have seen), even in the highest, the actions of the heart and of the alimentary canal. These, in the lowest tribes, probably bear a much greater proportion to the whole amount of those exhibited by the beings, than they do in the higher; whilst those which we may regard as specially dependent on a nervous system, appear to constitute but a small part of their general vital actions. The life of such beings, therefore, bears a much closer resemblance to that of the Vegetable, than to that of the higher Animal. Their organic functions are performed with scarcely more of sensible movement than is seen in plants; and of the motions which they do exhibit (nearly all of them *immediately* concerned in the maintenance of the organic functions), it is probable that many are the result of the simple contractility of their tissues, called into action by the stimuli directly applied to them. It is scarcely possible to imagine that such beings can enjoy any of those higher mental powers, which Man recognises by observation on himself, and of which he discerns the manifestations in the tribes, which, from their nearer relation to himself, he regards as more elevated in the scale of existence. If we direct our attention, on the other hand, to the *psychical** operations of Man, as forming part of his general vital actions, we perceive that the proportion is completely reversed. So far from his organic life exhibiting a predominance, it appears entirely subordinate to his animal functions, and seems destined only to afford the conditions for their performance. If we could imagine his nervous and muscular systems to be isolated from the remainder of his corporeal structure, and endowed in themselves with the power of retaining their integrity and activity, we should have all that is essential to our idea of Man. But, as at present constituted, these organs are dependent, for the maintenance of their integrity and functional activity, upon the nutritive apparatus; and the whole object of the latter appears to be the supply of those conditions necessary to the exercise of the peculiarly *animal* functions. That his mental activity should be thus made dependent upon the due supply of his bodily wants, is a part of the general scheme of his probationary existence; and the first excitement of his intellectual powers is in a great degree dependent upon this arrangement.

102. The most simple, or elementary function of the Nervous System is,

* Here and elsewhere this term will be employed in its most extended sense, to designate *all* the mental operations,—whether intellectual, emotional, or instinctive,—of which man's nervous system is the instrument.

as already observed, the establishment of a communication between a part which is susceptible of impressions, and another which can perform contractile movements; so that a stimulus applied to one may immediately excite a respondent action in the other, however great may be its distance. Hence it may be said to have an *internuncial* function; but this, so far it is performed without the necessary participation of the consciousness or will of the individual, is not essentially higher in character than the corresponding function in Plants, although the latter is effected by a different apparatus. The ministration of the nervous system to purely Animal life, obviously consists in its rendering the mind cognizant of that which is taking place around, and in enabling it to act on the material world, by the instruments with which the body is provided for the purpose. It is curious to observe that every method at present known, by which mind can act upon mind, requires muscular contraction as its medium, and sensation as its recipient. This is the case, for example, not only in that communication which takes place by language, whether written or spoken; but in that less evident but not less eloquent converse, by which two minds "attuned to nature's sweetest harmony" can read each other's thoughts. The look, the touch, the gesture, which are so frequently more expressive than any words can be, are all the result of muscular contractions excited in the nervous centres; and thus we trace the limitation which, even in communication that appears so far removed from the material world, constantly bounds the operations of the most powerful intellect, and the highest flights of the imagination. That in a future state of being the communion of mind with mind will be more intimate, and that Man will be admitted into more immediate converse with his Maker, appears to be alike the teaching of the most comprehensive Philosophical inquiries, and of the most direct Revelation of the Divinity.

103. The Organs of Sense are instruments which are adapted to enable particular nerves to receive impressions from without; of a kind, and in a degree, of which they would not otherwise be sensible. Thus, although the simple contact of a hard body with the nerve may be readily conceived to produce a material change in it, of such a kind as would be easily propagated to the central sensorium, it is evident that a nerve must be peculiarly modified, to receive and conduct sonorous impressions from the undulations of the air, still more—the impressions produced by the undulations of that ethereal medium, to the vibrations of which most Natural Philosophers now attribute the transmission of light. And, even when this difficulty has been provided for by some modification in the structure of the nerve itself, there is evidently another still remaining,—that of understanding how distinct images of the form, colour, &c., of external objects can be communicated to the nerve of sight,—or ideas of the direction, pitch, quality, &c., of sonorous undulations can be obtained through the auditory nerve. There is reason to believe that many among the lower Animals, which do not *see* objects around them, are conscious of the influence of light; and thus the distinction between the mere reception of the impression, and the communication of the optical image, becomes evident. The former may take place through the intervention of nerves, whose sensory extremities offer no peculiarities; the latter can only be received through the medium of an instrument which shall, from the mixture of rays falling equally upon every part of a surface, produce an optical image, and then impress it upon the expanded surface of the nerve, so that each fibril may receive a distinct impression, the image presented to the mind being formed by the combination of the whole. That this is, in fact, the share which the organs of special

sense bear in the general endowments of the whole apparatus, may be inferred especially from the conformation of the Eye, which is in every respect a merely *optical* instrument of the greatest beauty and perfection, adapted to present to the nerve, in the most advantageous manner, the images of surrounding objects in all their variations; and we might conceive that, if it were possible for the interior of the living eye to be replaced by one constructed of inorganic materials by the hand of man, and for the retina to preserve its functional activity, the power of sight would be but little impaired, except through the incapability, on the part of any piece of human mechanism, to imitate those wondrous contrivances of Infinite Skill, which have for their object the adaptation of the instrument to varieties of distance, of intensity of light, &c.

104. There can be little doubt that the structure of the Ear is arranged to do the same for the sonorous vibrations, which the eye does for the rays of light; that is, through its means, the undulations which strike upon the external surface of the organ are separated and distinguished, those of a like kind being brought together upon one division of the nerve, and those of another order upon a different set of fibres; so that the different kinds of sound and the peculiar quality and direction of each may be discriminated, whilst by the concentration of all the impressions of the same character, a higher amount of force is given to them. Of the sense of smell, no similar account can be given; since the medium by which odours are propagated is not known. If, as is generally believed, this is accomplished by the diffusion through space, of minute particles of the odoriferous body itself (which supposition seems to derive support from the general fact, that the most volatile substances are usually most odoriferous*), smell may be regarded,—as taste also is probably to be considered,—in the light of a refined kind of touch. Thus, the general rule holds good, here as elsewhere, that the processes by which the organism is immediately brought into relation with the external world, are performed in obedience to physical laws;—the living structure only affording certain peculiar conditions, which may be imitated in a great degree by other means. This is the case, for example, with regard to Digestion, which is in itself a simply Chemical process, taking place out of the body as well as in it, if the materials and the necessary solvent be submitted to the same circumstances as those to which they are exposed in the stomach; and in regard also to that of Respiration, which depends upon the Physical tendency to mutual diffusion, inseparable from the existence of gases: and we notice the prevalence of the same general fact in the Animal as in the Organic Life. We cannot become cognizant of the changes, or even of the existence, of the external world, unless some material effect be produced by it on our organs of sense; nor can we produce any alteration in its condition, except by powers which act according to purely mechanical principles.

105. In regard to the Muscular System, it has already been sufficiently explained that it forms a part of the apparatus of Animal Life, no otherwise than as the instrument by which nervous energy operates upon external objects. The contractility which it manifests on the application of a stimulus, is an endowment which it derives from its own structure, and not from the nervous system; for it will be clearly proved in its appropriate place,

* Some of the most strongly odoriferous substances, however, are solids;—for instance, *musk*: and it has been experimentally proved, that the loss of weight, which follows the free exposure of a minute quantity of this perfume to an atmosphere constantly renewed during several years, is not appreciable by the finest balance.

that the presence of this contractility is connected with the healthy nutrition of the tissue and its due supply of arterial blood, and that the complete separation of any muscular part from all its nervous connections has none but an indirect influence on its properties.

CHAPTER III.

FUNCTIONS OF THE NERVOUS SYSTEM.

General Summary.

106. ALL our positive knowledge of the functions of the Nervous System is derived from observation of the movements exhibited by animals, and from our own consciousness of what passes within ourselves. Except through the movements consequent upon them, we have no means of ascertaining whether or not particular changes in the nervous system are attended with sensation. The cries and struggles of the animal made the subject of experiment, are ordinarily considered as indications of sensation; but it is not right so to regard them in every instance; nor are we justified in asserting that consciousness results from any external irritation, merely because movements evidently tending to get rid of this are performed in respondence to it. We know that the contractions of the heart and alimentary tube are ordinarily excited by a stimulus, without any sensation being involved; and these movements, like all that are concerned in the maintenance of the organic functions, have an obvious design, when considered either in their immediate effects, or in their more remote consequences. The character of *adaptiveness*, then, in muscular movements excited by external stimuli, is no proof that they are performed in obedience to sensation; much less, that they have a voluntary character. In no case is this adaptiveness more remarkable, than in some of those purely instinctive actions, which are not only performed without any effort of the will, but which the will cannot imitate. This is the case, for example, with the act of deglutition; the muscles concerned in which cannot be thrown into contraction by a voluntary impulse, being stimulated only by impressions conveyed from the mucous surface of the fauces to the medulla oblongata, and thence reflected along the motor nerves. No one can swallow, without producing an impression of some kind upon this surface, to which the muscular movements will immediately respond. Now it is impossible to conceive any movements more perfectly adapted to a given purpose, than those of the parts in question; and yet they are not only independent of volition, but of sensation,—being still performed in cases in which consciousness is completely suspended, or entirely absent.

107. There is much difficulty, then, in ascertaining the really elementary functions of the Nervous System, by experiments upon animals; and it is only when their results are corrected and explained by pathological observation on Man,—the only case in which we can obtain satisfactory evidence of the presence or absence of sensation, that they have much value to the physiological inquirer. From these combined sources, however, a vast

amount of knowledge of the functions of the nervous system has recently been gained; and the general purposes to which it is subservient may be advantageously stated in a systematic form, before we enter upon any detailed examination of them.

I. The nervous system receives impressions, which, being conveyed by its afferent fibres to the sensorium, are there communicated to the conscious mind. It is subservient in some way to the acts of that mind; and, as the result of these acts, a motor impulse is transmitted along the efferent trunks to particular muscles, exciting them to contraction. This motor impulse, however, may be either of an *emotional* or a *voluntary* character. We shall hereafter see reason to believe that, to these functions, the Encephalon and the nerves proceeding from it are subservient.

II. Certain parts of the nervous system receive impressions, which are propagated along afferent fibres, that terminate in ganglionic centres distinct from the sensorium; and in these a reflex motor impulse is thus excited, which, being conveyed along the efferent trunks proceeding from them, excites muscular contraction, without any necessary intervention of sensation or volition. Of this function (called by Dr. Hall, to whom the discovery of it is in great part due, the *reflex* function), we shall find that the portion of the Spinal Cord of Vertebrata which is not continuous with the fibrous structure of the brain, together with the portion of the nervous trunks which are connected with it alone, is the instrument.

III. Another division of the nervous system appears to have for its object, to combine and harmonize the muscular movements immediately connected with the maintenance of organic life, and to bring these into relation with certain conditions of the mind. There is reason to believe (though this is less certain) that it also influences, and brings into connection with each other, the processes of nutrition, secretion, &c.; though these, like the muscular movements just mentioned, are essentially independent of it.

108. Now, in reference to the first class of operations, it is well to explain that, though the physiologist speaks of the intellectual powers, moral feelings, &c. as *functions* of the Nervous System, they are not so in the sense in which the term is employed in regard to other operations of the bodily frame. In general, by the *function* of an organ, we understand some change which may be made evident to the senses, as well in our own system as in the body of another. Sensation, Thought, Emotion, and Volition, however, are changes imperceptible to our senses, by any means of observation we at present possess. We are cognizant of them in ourselves, without the intervention of those processes by which we observe material changes external to our minds; but we judge of them in others, only by inferences founded on the actions to which they give rise, when compared with our own. When we speak of sensation, thought, emotion, or volition, therefore, as functions of the Nervous System, we mean only that this system furnishes the conditions under which they take place in the living body; and we leave the question entirely open, whether the ψυχη has or has not an existence independent of that of the material organism, by which it operates in Man as he is at present constituted.

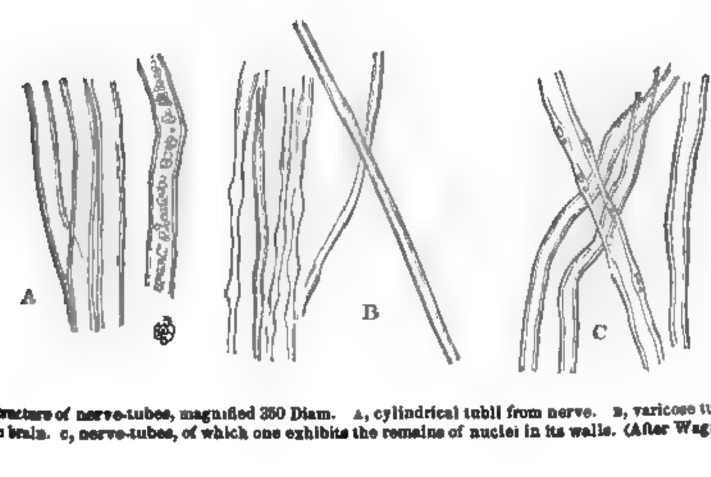
109. In regard to the second class of actions, it may be remarked, that they are nearly all connected, more or less closely, with the organic functions, or with the protection of the body from danger. Thus the movements of the pharynx supply to the stomach the alimentary materials it prepares for the nutrition of the body; those of the muscles of the thorax, &c. maintain that constant interchange of air in the lungs, which is necessary for the aeration of the blood: whilst those by which a limb is involuntarily retracted

from any cause of pain or irritation, are obviously adapted to the latter of these two ends.

Elementary Structure of the Nervous System.

110. Wherever a distinct Nervous System can be observed, it is found to consist of two kinds of structure; the presence of both of which, therefore, may be regarded as essential to our idea of it as a whole. One of these is that which is designated the *white* or *fibrous* matter. This constitutes (with the neurilema or nerve-sheath, and the cellular tissue which it encloses,) the whole of the nervous trunks, wherever they occur; and forms a large part of the central masses with which they are connected. It consists of tubes of great minuteness, which are filled with a kind of granular pith that can be squeezed from them. These tubes are for the most part cylindrical in the nervous trunks; and their pith is said to have such consistence, that it forms of itself a distinct fibre, which is divisible into numerous filaments. At some of the extremities of the nerves, these filaments may (according to Remak and others) be clearly distinguished; in the sensory papillæ they are said to form a series of loops, extending beyond the termination of the tube, but not diverging from it; whilst in the muscles they spread themselves more widely, forming a network of extreme minuteness. The diameter of the cylindrical tubuli is estimated to vary from about the 1-120th to the 1-240th of a line. A different structure has been described by Ehrenberg, as composing the bulk of the medullary substance of the brain, under the name of *varicose* tubes; and he states that these are also found largely in the spinal cord, and less abundantly in the nerves of special sense; but that they are seldom to be met with in the other trunks. These tubes were so named from their not being cylindrical, but presenting dilatations at intervals, so as to resemble a string of beads; and the appearance of these dilatations has given rise to the opinion, that the brain is composed of globules. It is now, however, satisfactorily shown that they are the result of the pressure and other manipulations to which the objects are subjected in preparation for the microscope; and that, if the nervous fibres of the brain and other parts are examined in a recent state, they are cylindrical, like those of the nervous trunks in general. Still there is some difference in their structure,

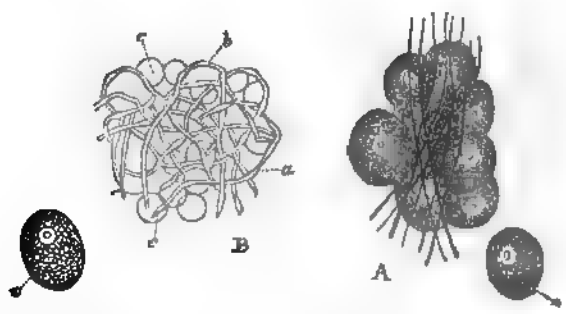
Fig. 7.



Structure of nerve-tubes, magnified 350 Diam. A, cylindrical tubli from nerve. B, varicose tubuli from brain. C, nerve-tubes, of which one exhibits the remains of nuclei in its walls. (After Wagner.)

since they exhibit this tendency to become varicose, which is elsewhere wanting. The walls of the fibre are not unfrequently seen to include the *nuclei* of the cells of which the tube was originally composed. Besides these tubular fibres, which constitute the white portions of the nervous matter, there are other filaments of a grey colour, and of much smaller diameter, without distinct cavities, which exist especially in the sympathetic nerves, but which may also be detected in others. These fibres may be termed *organic;* those existing in the sympathetic system of nerves may be traced to its ganglionic centres; whilst those which are formed in the cerebro-spinal nerves are connected with the ganglia upon their posterior roots.

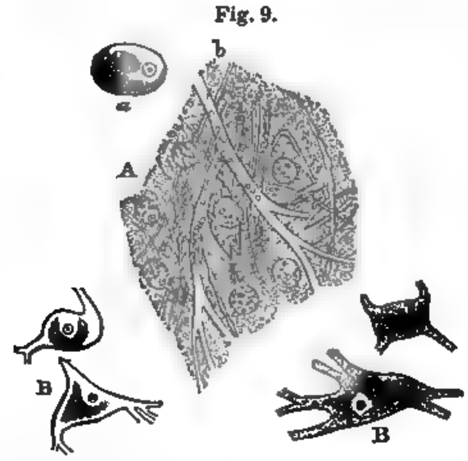
Fig. 8.



Primitive fibres and ganglionic globules. A, from sympathetic ganglion; * a separate vesicle, showing its pellucid nucleus and nucleolus. B, from grey substance of human cerebellum; *a, b*, plexus of primitive fibres; *c*, nucleated globules; * a separate globule from human Gasserian ganglion. 350 Diam.

111. The other elementary form of Nervous structure is termed the *cineritious* or *grey* matter. It seems to consist principally of a plexus of blood-vessels, in which the fibres of the former appear lost; and amongst

Fig. 9.



Primitive fibres and ganglionic globules of human brain, after Purkinje. A, ganglionic globules, lying amongst varicose nerve-tubes, and blood-vessels, in substance of optic thalamus; *a*, globule more enlarged; *b*, vascular trunk. B, B, globules with variously-formed peduncles, from dark portion of crus cerebri. 350 Diam.

these lie a number of granules or nucleated cells, which do not seem to have any definite arrangement. This substance is usually disposed in the *centre* of the larger masses, with which the nervous trunks are connected. It forms the *nuclei* of the ganglia which are the centres of the nervous system in the Invertebrata: it occupies part of the interior of the spinal cord of Vertebrated animals, which may be regarded as a chain of similar ganglia; and in the distinct ganglia which occur among the latter, it holds the same relative position. In the brain of Vertebrata, however, it is disposed externally, and forms a sort of coating to the mass beneath, which almost entirely consists of fibrous structure; hence it has been called the *cortical* substance, whilst the fibrous portion has been termed *medullary* matter.

112. There can be little doubt that the functions of these two divisions of the nervous system are different. That of the fibrous structure, as it exists in the nervous trunks, is unquestionably to conduct or convey the influence of changes, which have taken place elsewhere. And in accordance with what has previously been stated, of the mode in which the mind is brought into relation with the external world through this nervous apparatus, we find that there are (in the higher tribes of Animals, at least, if not in all) two sets of fibres: one of which has for its office to convey external impressions *towards* the nervous centres; whilst the other conveys the influence of these central organs to the structure at large, and especially to the muscular system. Hence it will be convenient to denominate the first *afferent* fibres, and the second *efferent*. These are to be regarded as general terms, expressing only the *direction* in which they propagate the changes to which they are subservient. The nature of these changes will be a subject of future inquiry.*

113. Every fibre, there is reason to believe, runs a distinct course, from the central organ, in which it loses itself at one extremity, to the muscle or organ of sense in which it terminates at the other. Each Nervous Trunk is made up of several fasciculi of these fibres; and each fasciculus is composed of a large number of the ultimate fibres themselves. Although the fasciculi occasionally intermix and exchange fibres with one another, (as occurs in what is termed a *plexus*,) the fibres themselves never inosculate. Each would seem, therefore, to have its appropriate office, which it cannot share with another. The objects of a plexus are twofold. In some instances it serves to intermix fibres which have endowments fundamentally different: for example, the spinal accessory nerve, at its origin, appears to be exclusively motor, and the roots of the par vagum are as exclusively sensory; but by the early admixture of these, a large number of motor fibres are imparted to the par vagum, and are distributed, in variable proportion, with its different branches; whilst few of its sensory filaments seem to enter the spinal accessory. In other instances the object of a plexus appears to be, to give a more advantageous distribution to fibres, which all possess corresponding endowments. Thus the brachial plexus mixes together the fibres arising from five segments of the spinal cord, and sends off five principal trunks to supply the arm. Now if each of these trunks had arisen by itself, from a distinct segment of the spinal cord, so that the parts on which it is distributed had only a single connection with the nervous centres, they would have been much more liable to paralysis than at present. By means

* The statement regarding the grey or organic fibres of the Nervous System, which is here made on the authority of Müller, Remak, and others, is somewhat more positive than observation has yet justified; the Author believes, however, that it will prove correct.

of the plexus, every part is supplied with fibres arising from each segment of the spinal cord; and the functions of the whole must therefore be suspended, before complete paralysis of any part can occur, from a cause which operates above the plexus. Such a view is borne out by direct experiment; for it has been ascertained by Panizza that, in Frogs, whose crural plexus is much less complicated than that of Mammalia, section of the roots of one of the three nerves which enter into it, produces little effect on the general movements of the limb; and that, even when two are divided, there is no paralysis of any of its actions, all being weakened in a nearly similar degree. It is not unlikely also that, by this arrangement, a *consentaneousness* of action is in some degree favoured, as is supposed by Sir C. Bell; for comparative anatomy shows that something resembling it may be traced, wherever a similar purpose has to be attained. Thus, in the Hymenoptera, there is a similar interlacement between the nerves of the anterior and posterior pairs of wings, which act very powerfully together; whilst in the Coleoptera, in which the anterior wings are converted into elytra, and are motionless during flight, the nerves supplying each pair run their course distinctly. In the Octopus, or Poulp, again, the trunks which radiate from the cephalic mass to the eight large arms surrounding the head, are connected by a circular band; forming a kind of plexus, which evidently contributes to the very powerful and harmonious movements of the arms of this Cephalopod. It is considered by Dr. Alison, that the origin of the trunks which supply the various muscles of the extremities, from several segments of the spinal cord, instead of one, has the further use of enabling the mind to vary, in greater degree than would otherwise be possible, the power with which the muscle shall be called into action; and this idea is certainly supported by the curious fact, that it is in the nerves of the extremities only that this plexiform arrangement prevails; and that the nerves of the eyeball, in whose action there is an equal degree of consentaneousness but far less variety of power, arise from single points of the cerebro-spinal axis. It is further considered by Dr. A. that the plexiform arrangement may enable the sensations proceeding from the muscles (which are important guides in their movement), to be more distinct, and consequently more easily discriminated from one another, than they would otherwise be; and there does not seem any reason why the same view should not be extended to the sensory impressions communicated from the general surface of the extremities.

114. In those Nervous Centres, of which the bulk is not great in proportion to the size of the nerves connected with them, there is commonly but little difficulty in tracing the fibres of the latter into their substance, and observing their termination in the grey matter of their nucleus. But, in the brain of the higher Vertebrata, and especially in that of Man, the case is somewhat different. The great mass of this organ is composed of fibres communicating between the different portions of its own cortical substance; and those which are connected with the nervous trunks cannot be so readily distinguished. Still there can be little doubt, that there is here, also, a conformity with the general proposition,—that each fibre, at its central termination, passes towards the grey matter, in which it loses itself, and maintains its distinctness from the rest, even through the most complex interlacement.

Elementary Functions of Nervous Structures.

115. As the structure of the Medullary matter of the Brain and Spinal cord does not present any essential difference from that of the nervous trunks, and as a part of their fibres are continuous with those of the latter,

there appears some ground for the belief, that the function is the same in both instances; and that the tubular fibres, wherever they present themselves, serve as *conductors* of the changes, which take place (usually at least) at one of their extremities. We then come to inquire how these changes are *originated;* and, finding at the central extremity a substance of peculiar character, and evidently (from the quantity of blood sent to it) the seat of important and energetic operations, we are naturally led to inquire if any such structure can be detected in the peripheral terminations of the nervous fibres. Microscopic examination of those which are connected with sensory organs, shows that they come into relation with a substance very analogous to the grey matter of the centres, though its elements are somewhat differently arranged. It is evident, both in the retina, the expansion of the auditory and olfactory nerves, and in the papillæ of the skin and tongue, that the fibres terminate in close approximation with a vascular plexus; and a granular structure is always present, which seems (as in the cortical substance of the brain) to be intermediate between these. We may regard this point, therefore, as the *origin* of the *afferent* fibres; and it would seem to be here, that those changes are effected by external impressions, which are propagated by the fibres to the central organs. Now it is an interesting discovery, recently made by Foville, that the fibres which radiate from the *sensory* tract of the medulla oblongata towards the cortical substance of the hemispheres, *do not terminate* in it; but that they form a series of loops, passing through it and converging again towards the centre from which they had diverged. Some of these loops do not reach the exterior of the hemispheres, but pass through the isolated tracts of grey matter which the brain contains.

116. On the other hand, the influence which produces muscular contraction is transmitted *from* the central organs, and probably from their grey matter; and this we may regard as the *origin* of the *efferent* fibres. These efferent fibres are distributed on the muscles nearly in the same manner that the afferent spread through the brain; that is, they do not terminate in free extremities, but a series of returning loops is formed by them.

117. It may be argued against this view of the respective functions of the granular and fibrous structures, that sensation may be produced by pinching an afferent trunk in its course, and that motion may be excited by irritating an efferent nerve; so that the changes, which have been spoken of as occurring at their points of origin in the vascular plexus, are not to be regarded as the means by which such influences are produced. But this argument will have little weight, when it is recollected that, on the same ground, we might infer that neither the organs of sensation, on the one hand, nor any part of the brain, or spinal cord, on the other, are the sources of the changes in question. The effects are obviously due to the fact, that the artificial stimulus imitates the natural one; and thus it is that, if a sensory nerve be compressed, the sensation produced is referred to the part of the surface to which its branches are distributed.

118. The belief that all changes in the nervous system, whether they take place at the centre or at the periphery, originate at the points in which the fibres come into relation with the vascular plexus, derives confirmation from the well-known dependence of these changes upon the activity of the circulation through the part at which they occur. Thus, if the circulation of blood through the brain be suspended for an instant, insensibility supervenes. If the cause of suspension be local only, the remainder of the nervous system may still be excited to action. This was the case in experi-

ments made by Sir A. Cooper. After having tied both carotid arteries in a dog, he compressed the vertebral trunks, and immediate insensibility resulted, proving the inactive condition of the brain; whilst convulsions also occurred, showing that the functions of the spinal cord were not suspended, but only deranged. But if, as in syncope, the circulation through the spinal cord also be weakened, its power of producing motions in respondence to impressions is diminished in like proportion. In the same manner, the production of impressions on the peripheral origins of the afferent nerves appears equally dependent upon the active influence of the vascular system. Every one knows that cold, which retards the circulation of blood through the skin, diminishes also its sensibility; and obstruction to the circulation by any other cause, such as pressure on the arterial trunks, produces the same effect. We have no opportunities of observing such affections of the *special* sensory organs, except when the whole supply of blood to the head is checked; and then, as the brain is also affected, there is no proof that the absence of sensation is partly due to the suspension of *their* impressibility, though it can scarcely be doubted that this is the case. Moreover, it is always found that an increase in local circulation is accompanied by an exaltation of the sensibility of the part. This may be especially noticed in the genital organs of animals during the period of heat; and in those of man when in a state of venereal excitement. It may be remarked, also, in those affections so closely bordering upon inflammation, to which the term *active congestion*, or *determination of blood*, has been applied. The pain which usually accompanies inflammation may be partly referred to this source; but it seems principally dependent upon other causes.

119. Our simplest idea, then, of a nervous system, includes a Central organ, of which the grey matter, formed by the intermixture of nervous fibres and blood-vessels, is the essential part; and an *afferent* and *efferent* set of fibres connected with it,—one conveying to it the impressions produced by external changes upon the periphery (where also the nervous structure comes into peculiar relation with the vascular system),—and the other conducting from it the motor stimulus, originating in itself, to the contractile tissue. This is precisely what we find in the lowest animals, in which a nervous apparatus can be distinguished, as will be hereafter explained. At present it will be desirable to consider some other questions, which early present themselves in the study of Neurology.

Mode of determining the functions of Nerves.

120. Various methods of determining the functions of particular nerves present themselves to the physiological inquirer. One source of evidence is drawn from their anatomical distribution. For example, if a nervous trunk is found to lose itself entirely in the substance of muscles, it may be inferred to be chiefly, if not entirely, motor or efferent. In this manner, Willis long ago determined that the third, fourth, sixth, portio dura of the seventh, and ninth cranial nerves, are almost entirely subservient to muscular movement; and the same had been observed of the fibres proceeding from the small root of the fifth pair, before Sir C. Bell experimentally determined the double function of that division of the nerve, into which alone it enters. Again, where a nerve passes through the muscles, with little or no ramification among them, and proceeds to a cutaneous or mucous surface, on which its branches are minutely distributed, there is equal reason to believe that it is of a sensory, or rather of an afferent character. In this manner Willis came to the conclusion, that the fifth pair of cranial nerves

differs from those previously mentioned, in being partly sensory. Further, where a nerve is *entirely* distributed upon a surface adapted to receive impressions of a *special* kind, as that of the Schneiderian membrane, the retina, or the membrane lining the internal ear, it may be inferred that it is not capable of transmitting any other kind of impressions; for experiment has shown that the *special sensory* nerves do not possess common sensibility. The case is different, however, in regard to the sense of taste, which originates in impressions not far removed from those of ordinary touch, and it is probable that the same nerves minister to both. Anatomical evidence of this kind is valuable also, not only in reference to the functions of a principal trunk, but even as to those of its several branches, which, in some instances, differ considerably. Thus, some of the branches of the par vagum are especially motor, and others almost exclusively afferent; and anatomical examination, carefully prosecuted, not only assigns the reasons for these functions, when ascertained, but is in itself nearly sufficient to determine them. Thus the superior laryngeal nerve is distributed almost entirely upon the mucous surface of the larynx, the only muscle it supplies being the crico-thyroid; whilst the inferior laryngeal or recurrent is almost exclusively distributed to the muscles. From this we should infer that the former is an afferent, and the latter a motor nerve; and experimental inquiries (hereafter to be detailed) fully confirm this view. In like manner it may be shown, that the glosso-pharyngeal is chiefly an afferent nerve, since it is distributed to the *surface* of the tongue and pharynx, and scarcely at all to the muscles of those parts; whilst the pharyngeal branches of the par vagum are chiefly, if not entirely, motor. Lower down, however, the branches of the glosso-pharyngeal cease, and the œsophageal branches of the par vagum are distributed both to the mucous surface and to the muscles; from which it may be inferred that they are both afferent and motor—a deduction which experiment confirms.

121. We perceive, therefore, that much knowledge of the function of a nerve may be obtained from the attentive study of its ultimate distribution: but it is necessary that this should be very carefully ascertained, before it is made to serve as the foundation for physiological inferences. As an example of former errors in this respect, may be mentioned the description of the portio dura of the seventh, at first given by Sir C. Bell: he stated it to be distributed to the skin as well as to the muscles of the face, and evidently regarded it as in part an afferent nerve, subservient to respiratory impressions as well as motions. In the same manner, from inaccurate observation of the ultimate distribution of the superior laryngeal nerve, it was long regarded as that which stimulated to action the constrictors of the glottis. But the knowledge obtained by such anatomical examinations alone is of a very general kind; and requires to be made particular,—to be corrected and modified,—by other sources of information. One of these relates to the connection of the trunks with the central organs. The evidence derived from this source, however, is seldom of a very definite character; and, in fact, the functions of particular divisions of the nervous centres have been hitherto rather judged of by those of the nerves with which they are connected, than have afforded aid in the determination of the latter. Still, this kind of examination is not without its use, where there is reason to believe that a particular tract of fibrous structure has a certain function, and the office of a nerve whose roots terminate in it is doubtful. Here again, however, very minute and accurate examination is necessary, before any sound physiological inferences can be drawn from facts of this description; and many instances might be adduced to show, that the real connections of

nerves and nervous centres are often very different from their apparent ones.

122. Experimental inquiries into the functions of particular nerves are also liable to give fallacious results, unless they are prosecuted with a full knowledge of all the precautions necessary to insure success. Some of these will be here explained. Suppose that, upon irritating the trunk of a nerve, whilst still in connection with its centre, muscular movements are excited; it must not be hence concluded that the nerve is an efferent one, for it may have no *directly* motor powers. The next step would be to divide the trunk, and to irritate each of the cut extremities. If, upon irritating the end separated from the centre, muscular contractions are produced, it may be safely inferred that the nerve is, in part at least, of an efferent character. Should no such result follow, this would be doubtful. If, on the other hand, muscular movement should be produced by irritating the extremity nearest the centre, it will then be evident, that it is occasioned by an impression conveyed *towards* the centre by *this* trunk, and propagated to the muscles by some other; in other words, to use the language of Dr. M. Hall, this nerve is an excitor of motion, not a direct motor nerve. The glosso-pharyngeal nerve has been satisfactorily determined to be chiefly, if not entirely, an afferent nerve, by experiments of this kind performed by Dr. J. Reid.

123. It has been from the want of a proper mode of experimenting, that the functions of the *posterior* roots of the spinal nerves have been regarded as in any degree motor. If they be irritated, without division of either root, motions are often excited; but if they be divided, and their separated trunks be then irritated, no motions ensue; nor are any movements produced by irritation of the roots in connection with the spinal cord, if the *anterior* roots have been divided. Hence it appears that the motor powers of these fibres are not direct, but that they convey an impression to the centre, which is reflected to the muscles through the anterior roots. Another source of fallacy is to be guarded against, arising from the communication to a nerve, in its course, of properties it did not possess at its root, by inosculation with another nerve. Of this many instances will hereafter present themselves.

124. The same difficulties do not attend the determination of the *sensory* properties of nerves. If, when the trunk of a nerve be pricked or pinched, the animal exhibits signs of pain, it may be concluded that the nerve is sensible to ordinary impressions at its peripheral extremity. But not unfrequently this sensibility is derived by inosculation with another nerve, as is the case with the portio dura, which is sensory after it has passed through the parotid gland, having received there a twig from the fifth pair. A similar inosculation explains the apparent sensibility of the *anterior* roots of the spinal nerves. If these be irritated, the animal usually gives signs of uneasiness; but if they be divided, and the cut ends nearest the centre be irritated, none such are exhibited; whilst they are still shown, when the farther ends are irritated, but not if the posterior roots are divided. This seems to indicate that, from the point of junction of the two roots, sensory fibres derived from the posterior root pass backwards (or towards the centre) in the anterior; and thus its apparent sensory endowments are entirely dependent upon its connection with the posterior column of the spinal cord, through the posterior roots.

125. The fallacies to which all experiments upon the nerves are subject, arising from the partial loss of their powers of receiving and conveying impressions, and of exciting the muscles to action, after death, are too obvious to require particular mention here; yet they are frequently overlooked.

Of a similar description are those arising from severe disturbance of the system, in consequence of operations; which also have not been enough regarded by experimenters.

Nature of the Changes in the Nervous System.

126. Of the actual nature of the changes by which impressions are received upon the peripheral origins of the afferent nerves, or communicated to the central origins of the motor, and are conducted along each to their opposite extremities, physiologists have no certain knowledge. That they are electrical has been, and still continues to be, a favourite theory with some; and that there is a great *analogy* between the propagation of nervous and that of electrical influence cannot be denied. But the reasons in favour of their *identity* are not greater, than those which might be adduced to prove that nervous influence is identical with other physical forces; since mechanical and chemical stimulation will, equally with electricity, imitate to a certain extent the natural changes in this system. On the other hand, there are many valid reasons against such a supposition; of which one is, that by putting a ligature round a trunk, its functions as a conductor of nervous influence are paralyzed, whilst it is still capable of conveying electricity. The various fibrils, too, are not as completely insulated from each other in regard to the passage of electricity, as we know them to be in respect to nervous agency. To the influence (whatever its nature may be) which the nerves convey, the term *vis nervosa* has been provisionally applied; and it is convenient to employ a term of this nature, when the laws according to which it operates are being specified. It must be remembered, however, that nothing is really gained by the use of such a term, which resembles one of the unknowu quantities in algebra. It is quite possible that the changes in the afferent nerves may differ from those that take place in the efferent; and that the changes which convey some kinds of impressions through the former, may differ from those concerned in others. No real progress is made, therefore, by attributing any phenomena of the nervous system to the vis nervosa; any more than by referring the various material changes in the organism to the operation of the *vital principle.* The laws according to which these changes take place are, however, legitimate subjects for physiological investigation. Those regulating the propagation of nervous agency may be briefly stated as follows. They evidently result from the facts already mentioned respecting the isolated character of each fibril, and the identity of its endowments through its whole course. They are here stated, with some modification, in the language of Müller.

I. When the whole trunk of a sensory nerve is irritated, a sensation is produced, which is referred by the mind to the parts to which its branches are ultimately distributed; and if only part of the trunk be irritated, the sensation will be referred to those parts only supplied by the fibrils it contains. This is evidently caused by the production of a change in the sensorium, corresponding with that which would have been transmitted from the peripheral origins of the nerves, had the impressions been made upon them. Such a change only requires the integrity of the afferent trunk between the point irritated and the sensorium; and is not at all dependent upon the state of the extremity to which the sensations are referred. This may have been paralyzed by the division of the nerve; or altogether separated, as in amputation; or the relative position of its parts may have been changed. It results from the foregoing, that, when different parts of the thickness of the same trunk are separately subjected to irritation, the sensations are succes-

sively referred to the several parts supplied by these divisions. This may be easily shown by compressing the ulnar nerve, in different directions, where it passes at the inner side of the elbow-joint.

II. The sensation produced by irritation of a branch of the nerve is confined to the parts to which that branch is distributed, and does not affect the branches which come off from the nerve higher up. The rationale of this law is at once understood; but it should be mentioned that there are certain conditions, in which the irritation of a single nerve will give rise to sensations over a great extent of body. This is due, however, to a particular state of the central organs; and not to any direct communication among the sensory fibres.

III. The motor influence is propagated only in a centrifugal direction, never in a retrograde course. It may originate in a spontaneous change in the central organs: or it may be excited by an impression conveyed to them by afferent nerves; but in both cases its law is the same.

IV. When the whole trunk of a motor nerve is irritated, all the muscles which it supplies are caused to contract; but when only a part of the trunk or a branch is irritated, the contraction is confined to the muscles which receive their nervous fibres from it. This contraction evidently results from the similarity between the effect of an artificial stimulus applied to the trunk in its course, and that of the change in the central organs by which the vis nervosa is ordinarily propagated. In this instance, as in the other, there is no lateral communication between the fibrils.

Comparative Anatomy and Physiology of the Nervous System.

127. Although the structure and distribution of the Nervous System in the different classes of Animals have been, until recently, but little appealed to in the determination of its functions, they are capable of supplying evidence regarding some of these, not less important in its character, than that which Comparative Anatomy affords to other departments of Physiology. Some of the principal of these contributions will now be pointed out.

128. In the lowest tribes of the RADIATED division of the animal kingdom, no nervous system has yet been discovered. These have, therefore, been separated by some naturalists into a new primary group, to which the designation of *Acrita* has been given, on account of the (supposed) "*indistinct*, diffused, or molecular character of their nervous system." This idea of a "diffused nervous system" seems to be regarded by many—physiologists as well as naturalists—as the necessary alternative, resulting from the want of any definite indications of its presence. It may be said, however, to be based on very erroneous notions, as to the true offices of the nervous apparatus. Its influence is not required to endow the tissues with *contractility;* a property possessed in a high degree by the structures of many Plants, to which these beings present a much greater *general* resemblance, than they bear to the higher Animals; and, even in the latter (as will be shown hereafter), this property is independent of "nervous agency," although generally called into exercise by it. That a nervous system is not required by them for the performance of the functions of Nutrition and Reproduction, otherwise than to supply, by its locomotive actions, the conditions of those functions, would also appear from its absence in Plants. It is on the sensible movements of these beings, that our belief in their possession of a nervous system must be founded, when we cannot render it cognizable by our senses. But we must be careful not to draw hasty inferences from such phenomena. Sensible movements are, as we have seen,

performed by the Dionæa and Sensitive plant, in respondence to external stimuli acting on distant organs; and here the channel of communication is probably the vascular system. We observe, however, that even in Polypes an impression made upon one part (one of the tentacula, for example,) is propagated to distant parts, and excites respondent movements in them, more rapidly than we could imagine to occur, without such a channel of communication, as a nervous system *only* is known to afford. Moreover, some of their actions appear to show a certain degree of *voluntary* power, and therefore of consciousness; being independent, so far as can be ascertained, of the operation of external stimuli. These phenomena, then, would lead us to suspect the existence of a nervous system in the beings which exhibit them; not, however, in a "*diffused*" condition, but in the form of connected filaments. For, what consentaneousness of action can be looked for in a being, whose nervous matter is incorporated in the state of isolated globules with its tissues? How should an impression made on one part be propagated by these to a distance? And how can that consciousness and will, which are *one* in each individual, exist in so many unconnected particles? If, then, we allow any sensibility, consciousness, and voluntary power, to the beings of this group of Acrita—to deny which would be in effect to exclude them from the Animal Kingdom—we must regard these faculties as associated with nervous filaments, of such delicacy as to elude our means of research. When the general softness of their textures, and the laxity of structure which characterizes the nervous fibres in the lowest animals in which they *can* be traced, are kept in view, little difficulty need be felt in accounting for their apparent absence. The case is very different from that of Vegetable structure, the greater consistency of which enables us to place much more reliance upon the negative evidence afforded by anatomical research.

129. The correctness of this view (which has been here dwelt on the longer, because it involves a fundamental question in Nervous Physiology) is borne out by the fact, that, in those members of the group whose size and consistency allow their structures to be sufficiently examined, a definite nervous system has been detected, in the position which it might, *à priori*, be expected to occupy, according to the type of the individual. Thus, in the large fleshy isolated polype, commonly known as the Sea-Anemone (*Actinia*), a nervous ring has been discovered, surrounding the mouth as in other Radiata, and sending off branches to the tentacula, with a minute ganglionic enlargement at the base of each. In the higher Radiata, as the *Star-Fish*, the nervous system has the same regular form as that which prevails through the other organs. The mouth is surrounded by a filamentous ring, which presents a regular series of ganglionic enlargements, of which one corresponds with each segment of the body. From every one of these, a branch is transmitted to the corresponding ray; and two smaller ones proceed to the viscera included in the central disk.

130. The *Polypifera* being the lowest of the Radiated classes in which there is a regularly-organized digestive apparatus, and which perform movements of a character ascribable only to a nervous system, it will be desirable to inquire a little more particularly into the phenomena they exhibit, and the degree in which these necessarily involve the possession of the higher mental endowments. In this inquiry we shall refer principally to the little *Hydra*, or fresh-water polype, the habits of which are better known than those of any other species. Although no nervous filaments have been detected in this, we have a right to infer their presence for the reasons already given; and they probably form a ring around the mouth, as in the Actinia,

sending filaments to the tentacula. This interesting little being may be regarded as essentially a *stomach;* and the orifice of this is provided with tentacula, which contract when irritated by the touch of any adjacent body, and endeavour to draw it towards the entrance. Now, the action in the Human body, to which this is most allied, is evidently that of the muscles of deglutition, which lay hold, as it were, of the food that has been conveyed to the fauces, and carry it into the stomach. These muscles are called into action, not by an effort of the will, but by the contact of the food with the lining membrane of the pharynx. This *impression* is propagated by the glosso-pharyngeal nerve to the medulla oblongata, where a respondent motor impulse is excited, which is transmitted through the pharyngeal branches of the par vagum to the muscles of deglutition, and causes their contraction. This phenomenon will be more fully examined hereafter; it is adduced here simply as an instance of the important class of *reflex* movements, which are independent of the brain (though, to a certain extent, controlled by it), which are altogether involuntary, and which do not *necessarily* involve the production of sensation. There would appear to be little difference in the character of this movement, between the simple Hydra and the most perfect Vertebrated animal. In the latter, however, another set of muscles are superadded to these, for the purpose of preparing the aliment by mastication for the operations of the stomach, and of bringing it within reach of the pharyngeal constriction. But, it has been urged, the inactivity of the tentacula when the Hydra is gorged with food, proves that they are excited to action by the will of the animal. This inference, however, may be easily disproved. The muscles of deglutition in man are not called into action with nearly the same readiness and energy when the stomach is distended as when it is empty; a fact of which any one may convince himself, by observing the relative facility of swallowing at the commencement and the termination of a full meal. No one will assert that *this* variation is an effect of the will; indeed, it is often opposed to it; being one of those beautiful adaptations by which the welfare of the economy is provided for, but which the indulgence of the sensual appetites opposes. Most of the movements of this animal, and of others of the class, appear to be equally the result of external stimuli with that already described; and it is only in a few instances, principally those of absolute locomotion or change of place, that any evidence of *voluntary* action can be discerned. It may be occasionally remarked, however, that one or more of the tentacula are retracted or extended, without the slightest appreciable change in any of those external circumstances which seem ordinarily to affect the motions of the animal; and this action we can scarcely regard as otherwise than voluntary.

131. Thus in the Nervous System of Radiated Animals, we have an instance of that community of function, which is so remarkable in the organism of the lower tribes, when contrasted with the separation which is perceptible in those at the opposite extremity of the scale. The visceral nerves of the Asterias are not isolated at their central terminations from those which are connected with the sensorial and locomotive functions: nor are those which minister to the instinctive actions separable from those which convey the influence of the will. Every segment of the body appears equal in its character and endowments to the remainder; each has a ganglion appropriated to it; and, as the ganglia, like the segments, are all alike, neither of them can be regarded as having any *presiding* character.

132. From the Radiated we now pass to the MOLLUSCOUS classes; the general character of which, as a natural group, is the remarkable predominance of the nutritive system over that of animal life. In fact, although

the organs which minister to their vegetative functions attain a very high degree of development, the animal powers of sensation and locomotion are, in general, so feebly manifested, as to show that they are entirely subservient to the exercise of the former. There is not in the Mollusca, as in the Radiata, any repetition of parts around a common centre; and we do not therefore meet in them with a number of ganglia nearly or altogether alike in endowments. In some of the higher species there is a conformity between the two sides of the body, or a lateral symmetry, which involves a subdivision of some of the ganglia, that are single in the inferior tribes, into two masses, which always remain in connection with each other. With this exception, it may be observed, that all the ganglia, to the number of four or five, which we meet with in the higher Mollusca, appear to have distinct functions; as may be determined by tracing the distribution of their nerves. Thus we find a pair of *cephalic ganglia*, situated above the œsophagus, connected with the organs of special sensation, and sending motor nerves (as we shall see reason to believe) to all parts of the body. This is obviously analogous to the brain of Vertebrata. Below the œsophagus there is generally a small ganglion, connected with the apparatus of deglutition, which may be called the *stomato-gastric* ganglion. In connection with the gills we have always one ganglion, sometimes a pair, which may be termed the *branchial* ganglion. Another is found at the base of the foot, which may be called the *pedal* ganglion. And there is sometimes another, which especially supplies the mantle with nerves; and this may be called the *palleal* ganglion. The distribution of their nerves to the different organs would alone indicate their respective functions; but these are placed beyond doubt, by that very great variety in the disposition of these organs, which is characteristic of the Mollusca. The development of the sensory organs, the situation of the gills, the structure and position of the foot, the conformation and uses of the mantle, are well known to differ in the most obvious manner, in genera which are closely allied to each other. Hence the anatomist is able, by the discovery of corresponding changes in the nervous system, to satisfy himself of the particular functions of its different centres.

133. It is only in the higher tribes, however, that this separation of function is evident; and it may be especially noticed in the class GASTEROPODA; which is so named from the presence of a kind of *foot*, or locomotive organ, on the underside of the body,—this being formed by a thickening of the muscular part of the mantle in that situation. Of the animals belonging to this class, some form *univalve* shells, whilst others are entirely shell-less. They are much superior in general organization to the animals inhabiting *bivalve* shells, which are included in the class Conchifera; and this superiority manifests itself strongly in the development of the powers of locomotion and sensation. The Conchifera belong to the group of *Acephalous*, or headless Mollusca; the mouth not being placed upon a prominent part of the body, nor guarded with organs of special sensation. The lowest form of this group consists of the class Tunicata, composed of animals in which the whole body is enclosed in a tunic or bag, having but two orifices, through one of which the water is drawn in by ciliary action, whilst through the other it is expelled. This bag forms a large chamber, the lining of which is devoted to the respiratory function; and at the bottom of it lie the mass of the viscera, and the true mouth or entrance to the stomach. A part of the water which is taken into the respiratory chamber flows into this, and passes through the intestinal canal, being discharged along with that which has only served the purpose of aerating the blood. These animals have no power of motion but such as is effected by the general contraction

of the respiratory sac, which is effected by a single ganglion placed between its orifices, which is therefore chiefly a *branchial* ganglion; and this is the only nervous centre they possess. Although none of the GASTEROPODA are able to execute very active movements, few are entirely fixed; all are more or less dependent upon the exercise of these powers for their supply of food; and the higher tribes employ them also in the perpetuation of the race, since the connection of two individuals is in them an essential part of this function. Although the foot is the chief instrument of locomotion, some of the naked aquatic species have other means of propelling themselves. These move through the water by the undulations of their whole bodies, like the leech, or the vermiform fishes; and a few appear materially assisted by an expansion of the mantle on the anterior part of the body, which contains muscular fibres, and seems to act as a fin. In every division of the Animal Kingdom, we find the development of special sensory organs to bear a close relation with that of the locomotive apparatus. In the present instance, we observe an evident example of this general rule. The organs of vision, which, when existing at all among the Conchifera, were very imperfect, are here almost constant and more highly developed; the tentacula are more sensitive, and are sometimes increased in number to six or eight; and there is reason to believe that some of them occasionally minister to the sense of smell. These senses, as well as the locomotive powers of the animals, have an obvious relation with the supply of the digestive system, which is not here, as in the inferior classes, dependent upon the miscellaneous aliment conveyed to the mouth by the movement of the surrounding fluid medium, but is more limited as to the character of the food to which it is adapted; so that the animal requires the means of becoming acquainted with the proximity of what it can digest.

134. It is not a little curious, however, that, although the general surface appears highly susceptible of impressions, which excite responsive movements adapted to fulfil some important office in the economy, it does not seem to be susceptible of *painful* impressions in any thing like the same degree. This, which cannot but be regarded as a beneficent provision for the happiness of animals so incapable of offering any active resistance to injury, would appear from the observations of various experimenters, and especially from the testimony of M. Ferussac, who says, "I have seen the terrestrial Gasteropods allow their skin to be eaten by others, and, in spite of large wounds thus produced, show no pain." This fact has an important bearing on our general views of the operations of the nervous system; since it would seem to confirm an opinion founded upon other phenomena, that the *impressions*, which produce reflex actions through the nervous system, do not always involve the production of *sensation*. Thus, cases of paralysis of the lower extremities have occurred in the human subject, in which no sensibility existed in the limbs, nor had the will any power to move them; yet irritation applied to the soles of the feet, of which the patient was not conscious, produced retractile movements in the legs. This question, however, will be more fully discussed hereafter.

135. The nervous system of the Gasteropoda consists of at least three distinct centres, the relative position of which varies with that of the organs which they supply. The *anterior* or *cephalic* ganglia are larger in proportion to the rest, than in the Conchifera; and they exhibit a tendency to gain a position anterior to the œsophagus, and to approximate towards each other, so as to meet and form a single ganglionic mass on the median line. The *branchial* ganglion is constantly to be met with; but its position is extremely variable. This centre, however, always bears a close relation with the

gills, both in situation and degree of development; and even where conjoined, as it frequently is, with the *pedal* ganglion, it may be distinguished from it by the distribution of its nerves, as well as by its separate connection with the cephalic ganglia, which is always noticed in such cases. This may be observed in the *Patella* (limpet) and *Limax* (slug). Sometimes the functions of this ganglion are subdivided between two, of which one is still appropriated to the branchiæ, whilst the other is connected with the general surface of the mantle, and with the respiratory passages which are prolongations of it, and hence may be called the *palleal* ganglion. The position of the *pedal* ganglion (which is generally double in the Gasteropoda, though the foot is single), also varies, but in a less degree, since it is generally in the neighbourhood of the head. Besides these nervous centres, we find, in many of the Gasteropoda, a separate system connected with a very important set of organs, the gustatory and manducatory, which are but slightly shadowed out among the Conchifera. In these higher tribes, the œsophagus is dilated at its commencement into a muscular cavity; containing a curious rasp-like tongue, often supported upon cartilages, which serves to reduce the food; and sometimes furnished with horny maxillæ. The nerves which supply these do not proceed directly from the cephalic ganglia, but are a part of a distinct system, which sends its ramifications along the œsophagus and stomach, and which is occasionally connected with the first by inosculating filaments. This set of ganglia and nerves, which is even more important from its relative development in some other classes, and into the analogies of which in the nervous system of Vertebrata we shall hereafter inquire, may be called, from its distribution, the *stomato-gastric* system.

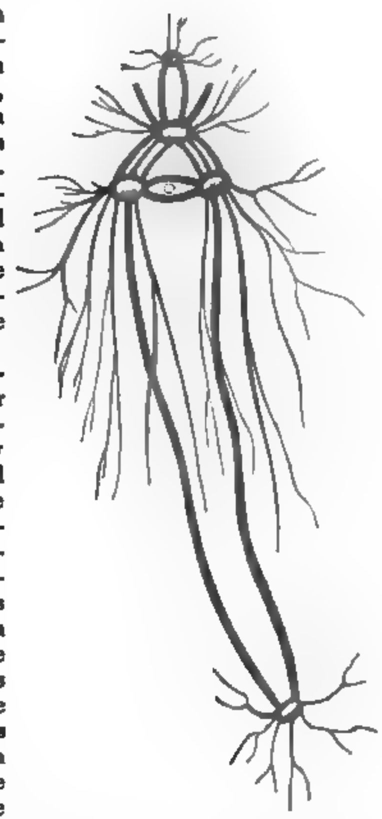
136. The manner in which the cineritious matter of the ganglia of the Mollusca is disposed, in reference to the nervous fibres which stand in relation to it, at once distinguishes these centres from the ganglia of the Sympathetic nerve of Vertebrata, or of the posterior roots of the spinal nerves, with which they have been sometimes compared. In the latter we observe the fibres *continued through* the ganglia, and the grey matter interposed amongst them. In the former, the grey matter is confined to the centre, and is *not traversed* by fibres; and the roots of the nerves which terminate in the ganglion are observed to penetrate to it, and then to diverge, becoming, as it were, lost in its substance; and this is alike the case with what are believed to be, from their connections, both sensory and motor nerves. This structure obviously resembles, therefore, that of the centres of the Cerebro-Spinal system in Vertebrata; and these ganglia may be regarded as corresponding with those parts of the nervous centres in the Vertebrata, the distribution of whose nerves is analogous. Thus the *branchial* ganglion obviously corresponds with that portion of the Medulla Oblongata, which is the centre of the respiratory actions in Vertebrata. The *pedal* ganglion is analogous to that division of the Spinal Cord, from which the nerves of the anterior or posterior extremity pass off. It is well known that such portions of the spinal cord may be completely isolated, without destroying the functions to which they minister. Thus, the brain and lower part of the spinal cord may be removed,—that portion only of the cerebro-spinal axis being left, which connects the principal respiratory nerves, in fact the *respiratory ganglion*,—and yet the animal may continue to exist for some time. It is then reduced to a condition similar to that of the Tunicata, whose single ganglion, though combining in some degree the functions of those which exist separately in the higher tribes, has evidently the regulation of the respiratory movements for its chief object. In the same manner, the integrity of the segment of the cord with which the nerves of the extremities are

connected, will enable them to execute those movements of a reflex character, which depend upon its power as their centre, even though it is isolated from every other part of the nervous apparatus. The *cephalic* ganglia must be regarded as analogous, not to any single portion of the Encephalon in Vertebrata, but in some degree to the whole. We find nerves of special sensation proceeding from them, certainly to eyes, perhaps also to olfactive organs; as well as others of common sensation, supplying the tentacula and mouth. Hence we must admit, that they perform the functions of the optic ganglia of Vertebrata, and perhaps also of the olfactory lobes; as well as of the portion of the medulla oblongata in which the sensory portion of the fifth pair terminates. Moreover, they certainly give origin also to motor nerves, and must thus perform the functions of the Medulla Oblongata, from which the corresponding nerves arise in Vertebrata, as well as, perhaps, of the Cerebellum. And, if we regard these animals as enjoying the perceptive, reasoning, and volitional faculties, in however low a degree, we must attribute to their cephalic ganglia some portion of the attributes of the cerebral hemispheres in the highest classes. This combination of function will not appear so extraordinary, when it is recollected that *all* the central operations of the nervous system are performed in the Tunicata by *one* ganglion; and in the Radiata by a series, of which each is but a repetition of the rest: and it is quite conformable to the general principle of the *gradual specialization* of function, which may be observed in ascending the scale of organization.

137. It is obvious that the portion of the Nervous system of the Gasteropod Mollusca, into the analogies of which we have thus inquired, cannot in the least be compared *as a whole* with the *Sympathetic* system of the Vertebrata, which it was formerly imagined to resemble. The distribution of some of its nerves to the viscera, however, may indicate that it partly performs the functions of that system, with which it is structurally intermixed, even in Vertebrata, as the late inquiries of Müller and others (of which the results will hereafter be stated) have shown. But the stomatogastric system may, perhaps, with more probability be considered as executing its offices. Into the peculiar character of that system we shall be more competent to inquire, when we have traced it through other classes of Invertebrata.

138. Having thus separately considered the nervous centres of the Gasteropoda, and determined their special functions by their structural relations, we shall inquire into the mode in which these functions are combined, so as to enable them to act in harmony. This is an inquiry of much interest, in reference to the determination of the offices of the different parts of the nervous centres in Vertebrated animals. If we examine the mode in which the different ganglia are united by connecting trunks, we are led to perceive the important fact that, while they have little or no communication with each other, they are all directly connected with the cephalic ganglia, which seems thus to harmonize and control their individual actions. Frequently such a communication with one another appears to exist, where there is really none. Thus, in the *Aplysia*, a cord passes from the branchial ganglion, which is situated in a posterior part of the body, to the pedal ganglion. Where such is the case, the trunk is not united with that which proceeds from the ganglion through which it passes; but the two remain distinct, though running in the same direction. Moreover, the double function of a ganglion may be sometimes recognized by its being connected with the cephalic mass by a double trunk. Thus, in the Aplysia, that which has been termed the *pedal* ganglion is really made up of a pedal and palleal

Fig. 10.



Nervous system of *Aplysia*. The most anterior ganglion is the *pharyngeal* and below this is seen the *cephalic*. The cephalic is connected, by three distinct cords on each side, with the *lateral* ganglia, which combine the functions of *pedal* and palleal centres; these are united with each other by two transverse bands, between which the aorta passes. From the lateral ganglia, a connecting cord passes backwards on each side to the *branchial* ganglion; this cord is continuous with one of the three proceeding from the cephalic ganglion.

ganglion, as is proved by the distribution of its branches; and in conformity with this double function, we find it communicating with the cephalic mass by two cords, besides the one which has been just mentioned as passing through it, and which appears as a third. In the *Bullæa*, whose nervous system is disposed on the same general plan, the pedal and palleal ganglia are separately connected with the cephalic; the cord from the branchial ganglion passing through the palleal.

139. Further, a careful examination of these ganglia, and of their connecting cords, discloses this important fact, which is peculiarly evident in the case of the pedal ganglia—that the cord does not lose itself in the grey matter of the ganglion, but divides itself into filaments, which mix with those proceeding from it, to form the nervous trunks which it distributes. We can scarcely, then, fail to infer, that the pedal ganglion, with the nervous fibrils proceeding from itself, is the source of the reflex actions of this organ; whilst the filaments which are continuous with those of the connecting trunk, and which are thus in relation with the nucleus of the cephalic ganglia, are the channels of sensory impressions, and of the motor impulses of volition. This is well illustrated in the very curious disposition of parts which we find in the arms of the Cuttle-fish. These are provided, as it is well known, with a series of suckers, which are to the animal important instruments of locomotion and prehension. It has been observed by Dr. Sharpey, that the nerves which supply these arms are provided with ganglionic enlargements, of which one corresponds with each sucker; and that each trunk consists of two tracts, in one of which the ganglionic enlargements exist: whilst the other passes continuously over these, but sends off nervous filaments, which help to form the branch going to each sucker. It has been supposed that the white or fibrous tract is the motor portion, and the ganglionic the sensory; but this is inconsistent with the facts known regarding the influence of the nerves upon the movements of the suckers. When the animal wishes to embrace any object firmly with its arm, it brings all the suckers simultaneously to bear upon it. There can be little doubt that this action is occa-

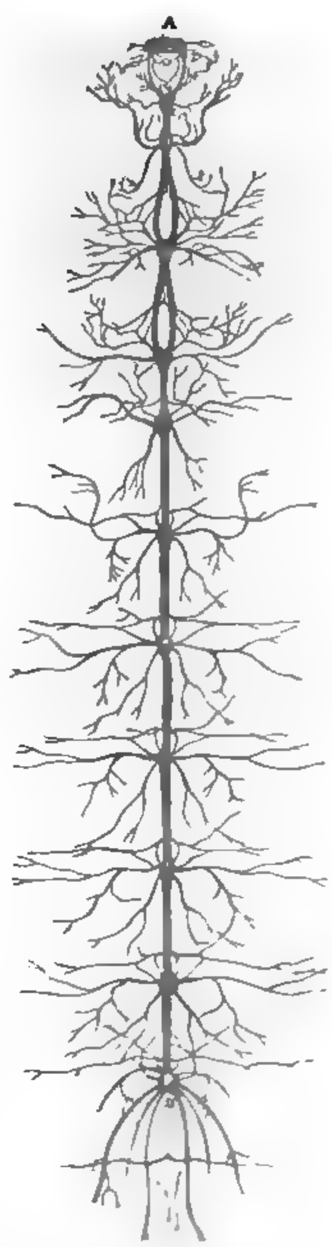
sioned by a motor impulse, propagated from the cephalic masses by the non-ganglionic portion of the cord, which supplies all the suckers alike. On the other hand, any individual sucker may be made to attach itself, by placing a substance in contact with it alone; this action is independent of the cephalic ganglia, as is evident from the fact, that it will take place when the arm is severed from the body, or even in a small piece of the arm, if recently separated; and it can scarcely be doubted, that it is due to the reflexion of the impression made upon the sucker, through the small ganglion in its neighbourhood, where it excites a motor impulse. The operation of these independent centres appears, in the entire living animal, to be controlled, directed, and combined, by the cephalic ganglia, through the medium of the fibrous band that passes over them, and mixes its branches with theirs. A very similar arrangement will be presently shown to exist in the double nervous column of the Articulata.

140. Upon reviewing all the anatomical facts hitherto stated, it will be perceived that ganglionic masses, characterized by nuclei of grey matter, or of something equivalent to it, seem to be placed wherever it is desirable that impressions made upon the afferent nerves should excite motions; and that, as we rise in the scale, there is an increase in the number of centres possessing a diversity of functions. We have seen that sometimes these centres are, for the sake of convenient disposition, united into one mass; whilst, on the other hand, when the organs are multiplied, they also are repeated to a like extent, especially when it is desirable that they should be able to act independently of one another, as in the case of the suckers of the Cuttle-fish. It may further be remarked, that, wherever the presence of special sensory organs, confined to one part of the body, gives to that part a predominance over the remainder (the entrance to the alimentary canal being always in this neighbourhood), we find the ganglia with which they are connected possessing a special relation with all the rest, which these do not possess with each other. It is obvious that, where visual organs are developed, the impressions made upon these will determine the movements of the animal, more than those of any other kind; and it would seem to be chiefly owing to the information they communicate, that the cephalic ganglion has such an evident presiding influence over the rest, even when smaller than any of them. This is, however, more the case in animals whose movements are rapid, and in which, therefore, the perception of distant objects is more important—as in the Insect tribes. Except in the Cephalopoda, the subservience of the nervous system to the nutritive functions of the Mollusca is so great, that it might almost be regarded as an appendage to the digestive organs, destined for the selection and prehension of aliment. But in the more active members of that class, it derives a more elevated character, from the development of organs of special sensation and of active locomotion.

141. A close relation may be traced between the predominance of the cephalic ganglion, and the evidence of the operations of sensation and volition, as manifested in the movements of the animal. So long as food is within its reach, we can scarcely regard the prehension of it as an act of any higher character than that of the infant when it applies its lips to the nipple of the mother; and this action is known (by observation of acephalous monsters, and by experiments on puppies, &c.) not to be dependent on the presence of a brain, and may therefore be regarded (as will subsequently appear) as not necessarily involving either sensation or volition, although, in the perfect state of the being, it is accompanied by the former. But, when the animal has to exercise its organs of special sensation, and to put its

general locomotive apparatus into activity for the purpose of seeking its aliment, its operations must be regarded as of a higher order. Still, many of these may be considered *instinctive;* that is to say, not involving any reasoning powers, or any notion of *purpose*, on the part of the animal itself, but more analogous to those involuntary actions, which result from the excitement of the emotions in Man. We may take a well-known case in illustration—the ejectment of the contents of the ink-bag which takes place when the Cuttle-fish is pursued. This has been represented by some as of a *voluntary* character, and as indicating a *design* on the part of the animal to conceal itself from its pursuers. But such a supposition involves an amount of reasoning power on the part of the animal which we can scarcely attribute to it; and, if the action were not performed to as much advantage the *first* time as it might be on a subsequent occasion, it would obviously be of little use. It may rather be likened to the expulsion of the contents of the rectum and bladder under the emotion of fear, which many of the Human species (in their schoolboy days especially) know by experience to result from an impulse uncontrollable by the will. This view of its character is strengthened by the fact, that the secretion of *ink* is really analogous to that of *urine*.

Fig. 11.



Nervous System of Larva of Sphinx Ligustri, after Newport. A, [illegible] tion of the 11th and 12th.

142. We shall now inquire how far these doctrines are applicable to the ARTICULATA. The animals composing this group all present, in a more or less evident degree, a division into segments, which have an obvious tendency to resemble one another, as in the Radiata. In those in which these segments differ but little (as in the Centipede, or the Caterpillar of the Insect) the nervous system is a repetition of similar parts, disposed, not in a circle, as in the Radiata, but in a continuous line. The most anterior of the ganglia, however, has an evident predominating influence over the rest, for the reason just specified; and this influence will be found, by comparison in other classes, to diminish with the loss, and to increase

with the development, of the faculties of special sensation which have their seat there. The locomotive powers are just as predominant in the Articulated series, as are the nutritive functions among the Mollusca. Accordingly, we find the development of the Nervous System to bear a special reference to them; and the sensori-motor divisions of it can be more distinctly separated, than in the Mollusca, from the portion which ministers to the organic functions.

143. The general arrangement of the Nervous System differs so little, except as to the degree of concentration of the ganglia, in the different classes of this sub-kingdom, that it is of little consequence what example we select. It will be convenient to take for illustration that of the Larva of the *Sphinx Ligustri*, or Privet Hawk-Moth, which has been minutely described by Mr. Newport. Here we observe a chain of ganglia running from one extremity of the body to the other, along the ventral surface, and in the median line. These ganglia are connected by trunks, which, on close examination, are seen to consist of two cords closely united. The cephalic ganglion is bilobed; evidently consisting of two masses, which are united on the median line. These receive the nerves of the eyes and antennæ; but they are still of small size, in accordance with the low development of the sensory organs. The ganglia of the longitudinal cord are nearly equal, from one extremity of the body to the other. Each sends off nerves to its respective segments; and the branches proceeding from the different ganglia have little communication with each other. The highest of them, situated just beneath the œsophagus, is connected with the cephalic masses by two cords, between which that canal passes, encircled, as it were, in a ring. When we examine one of the ganglia of the ventral cord, and the nerves which seem to originate from it, we find that each nerve has three series of roots: one of which terminates, as in the other cases, in the grey matter of the ganglion itself; another interlaces with those of the opposite side; whilst the third is *continuous* with a *fibrous* portion of the cord, which may be traced uninterruptedly to the cephalic ganglia. When the structure of the cord itself is analyzed, it is seen that the fibrous tract or column is throughout distinct from that which contains the ganglionic enlargements (Fig. 12, A); and that it does not contribute towards the formation of these, but passes over them (as was first observed by Mr. Newport), like the analogous trunk in the arms of the Cuttle-fish.

144. After what has been said of the offices which the ganglia perform in the Mollusca, and of the relation which they bear to the cephalic mass, we shall have little difficulty in understanding the character of the nervous apparatus in the Articulata, if our minds be unoccupied by any preconceived notion. When we examine into the actions of the ventral cord, we perceive that those of all its ganglia are similar to each other; being related only to the movements of their respective segments, and of the members which belong to them. In fact, these ganglia may be regarded as so many repetitions of the *pedal* or locomotive ganglion of the Mollusca. It is easily proved, that the movements of each pair of feet may be produced by that ganglion alone with which it is connected; since a single segment, isolated from the rest, will continue to perform these movements for some time, under favourable circumstances. If an Earthworm be cut in two, whilst crawling, each portion will continue to advance, though the anterior one only will permanently preserve its vitality. If a Centipede be divided into several portions under the same circumstances, each will execute motions of progression for some time. But it is evident that these must be placed, in the living animal, under some general control, by which the consenta-

neousness of action that is essential to regular locomotion may be produced. This is easily proved by experiment. If in a Mantis, for example, the nervous cord be divided between the first and second thoracic ganglia, so as to isolate the ganglionic centres of the posterior legs, the limbs will continue to move energetically, but not with a combined object, and no progression will take place. We can scarcely account for the exercise of this general control, otherwise than by attributing it to the fibrous tract, which connects each of the nervous trunks immediately with the cephalic ganglia, as in the Mollusca; and this must, therefore, conduct to the sensorium (whose seat is probably in the latter) the impressions which there produce sensations, and must convey downwards the locomotive impulse; whilst the ganglion of each segment, with the filaments proceeding from its nucleus, will form the circle necessary for the simply reflex actions of its members.

145. The independence of the segments of the Articulata, as far as their reflex actions are concerned, and their common subordination to one presiding centre of the will, are fully explained on this supposition. It is also quite conformable to the analogy both of the Mollusca and of Vertebrata. We have seen that, in the former, where the ganglia are more isolated from one another and from the presiding centre, each appears to be the centre of simply reflex actions occurring in the organ with which it is connected; but that a part of the nervous fibres which seem to enter it, really pass on to communicate with the cephalic mass, where alone, it may be surmised, *sensations* can be felt, and *voluntary* impulses excited. And on the other hand, in Vertebrata, we find the ganglionic or mixed portion of the spinal cord, and the simply fibrous tracts, performing functions respectively analogous: for, when any segment is isolated from the rest, reflex actions may be excited through it, in the production of which the white columns can scarcely participate;—these being structurally distinct from each other, and from the ganglionic portion of the cord, and continuous only with the fibrous portion of the brain: whilst pathology supplies us with numerous instances of the converse proposition, namely, the destruction of the ganglionic portion, without the functions of the parts below being impaired;—*their* ganglionic portion being segmentally independent, and their communication with the brain being maintained by a continuity of white or fibrous structure.

146. The number and variety of the reflex actions which take place in the Articulata after decapitation, is very remarkable; and they seem to have a consentaneousness proportioned to the closeness of the relation between the nervous centres in the respective species. Thus, in the Centipede, we find the ganglia of each segment distinct, but connected by a commissural trunk. Here an impression made *equally* upon the afferent nerves of *all* the ganglia, will produce a consentaneous action. Thus, if the respiratory orifices on one side of a decapitated Centipede be exposed to an irritating vapour, the body will be immediately flexed in the opposite direction; and if the stigmata of the other side be then similarly irritated, a contrary movement will occur. But different actions may be excited in different parts of the cord, by the proper disposition of the irritating cause. In the higher classes, however, where the ganglia of the locomotive organs are much concentrated, the same irritation will produce consentaneous motions in several members, similar to those which the unmutilated animal performs. In the *Mantis religiosa*, for example,—which ordinarily places itself in a very curious position, especially when threatened or attacked, resting upon its two posterior pair of legs, and elevating its thorax and the anterior pair, which are armed with powerful claws,—if the anterior segment of the tho-

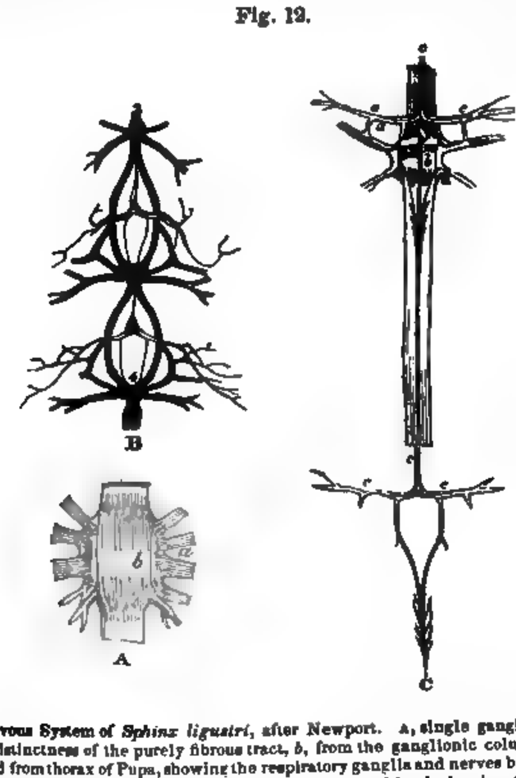
rax, with its attached members, be removed, the posterior part of the body will still remain balanced upon the four legs which belong to it, resisting any attempts to overthrow it; recovering its position when disturbed, and performing the same agitated movements of the wings and elytra, as when the unmutilated animal is irritated: on the other hand, the detached portion of the thorax, which contains a ganglion, will, when separated from the head, set in motion its long arms, and impress their hooks on the fingers which hold it. These facts prove unequivocally, that the automatic movements of these parts, which are performed in direct respondence to external impressions, are only dependent for their stimulation upon that ganglionic centre, with which the nerves that excite them are immediately connected. Another instance, related by Burmeister, is still more satisfactory in regard to the manner in which these movements are excited. A specimen of the *Dytiscus sulcatus*, from which the cephalic ganglia had been removed, and which remained in a motionless condition whilst lying with its abdomen on a dry hard surface, executed the usual swimming motions, when cast into water, with great energy and rapidity, striking all its comrades to one side by its violence, and persisting in this for half an hour.

147. Without describing in minute detail the forms which the nervous system presents in the higher classes of Articulata, or tracing that interesting series of changes which it undergoes during the metamorphosis of Insects, a few particulars may be stated on these subjects, as having an immediate bearing on our present object. The nervous system of the Larva, like that of the Annelida, or Myriapoda, presents an obvious relation with the means and extent of locomotion possessed by the animal. Each segment is equally concerned in locomotion; and with each is associated a *pedal* ganglion. None of the movements of the animal are very energetic; simple and slow progression is all for which its structure is adapted; and the uniformity in the actions of its legs would render it easy to combine them at the will of the animal, even though their respective centres remain so much isolated from one another. But, in the perfect Insect, the whole locomotive apparatus is concentrated in the thorax. The six legs (which are now all that remain), and the single or double pairs of wings, are all developed from its three segments; and a much greater variety of action is required, as well as more complete consentaneousness, on account of the increased number and velocity of the movements of the animal. We accordingly find that the ganglionic matter of the ventral cord of perfect Insects is more or less concentrated in the thoracic region; whilst the ganglia of the abdomen are usually few and small; the nerves to its segments, however, being given off as before at regular intervals. In some of the Coleoptera and Hemiptera, the concentration of the thoracic ganglia takes place to such an extent, that they seem to form but one mass; and this is the case also among some of the Crustacea, the different forms of whose nervous system are exactly parallel to those of their congeners among the inhabitants of the air and land. The nerves which supply the wings of Insects are found, in all stages of the development of these organs, to have a double origin. One root arises from the fibrous tract alone; whilst the other takes its origin from both tracts at the point of enlargement. When the ganglionic centres which supply the anterior and posterior pairs of wings remain distinct, there is a curious plexiform arrangement of their nerves, more or less intricate, according as the wings are destined to act with greater or less consentaneous energy, and absent when the anterior pair serve only as elytra, and do not assist in flight. This would remind us of the circular filament which was seen to connect the nerves of the arms in the naked Cephalopoda. Besides

these nerves, the wings are supplied from the respiratory system next to be described, from which scarcely any branches go to the legs. This will be readily understood, when it is considered that the wings are developed, as it were, out of an extension of the respiratory apparatus,* and that its actions are closely connected with these movements.

148. Hitherto we have spoken only of that division of the nervous system of the Articulata, which may be regarded as corresponding with the sensory and locomotive ganglia of the Mollusca; namely, the cephalic, the pedal, (and in some instances) the palleal. We have next to inquire what we find corresponding with the branchial ganglion. It is to be recollected that the respiratory apparatus of Insects is diffused throughout the whole body, so that its presiding system of nerves must be proportionally extended; and we are, therefore, prepared to find the *branchial* ganglion of the Mollusca repeated, like the pedal, in each segment. Besides the nervous trunks proceeding from the ventral cord at its ganglionic enlargement, we find, in most of the Articulated classes, a series of smaller nerves, given off at intermediate points, without any apparent swelling at the points of divergence. The connections of these are most distinctly seen in the thoracic region, just as the Larva is passing into the Pupa state; for the cords of the ventral column

Fig. 12.



Parts of Nervous System of *Sphinx ligustri*, after Newport. A, single ganglion much enlarged, showing the distinctness of the purely fibrous tract, *b*, from the ganglionic column, *a*. B, portion of the double cord from thorax of Pupa, showing the respiratory ganglia and nerves between the separated cords of the symmetrical system. C, view of two systems combined, showing their arrangement in the perfect Insect; *a*, ganglion of ventral column; *b*, fibrous tract passing over it, *c c*, respiratory system of nerves distinct from both.

* See Principles of General and Comparative Physiology, 2nd Ed. § 465.

then diverge, so that an additional tract may be seen, which occupies the central line. By a close scrutiny, this tract may be found in the perfect Insect, on the superior or visceral aspect of the cord; and these nerves are given off from minute ganglionic enlargements upon it. It seems to be quite unconnected along its whole course with the column upon which it lies. Its nerves, however, communicate with those of the sensori-motor system; but they have a separate distribution, being transmitted especially to the tracheæ, on the parietes of which they ramify minutely, and also to the muscles concerned in the respiratory movements. (The latter, however, being a part of the general locomotive apparatus, are also supplied from the principal ganglionic column.) These nerves, then, which are evidently analogous to those of the gills and siphonic apparatus in the Mollusca, may be regarded as corresponding with the pneumonic portion of the par vagum in Vertebrata—which is in like manner distributed on the air-passages,—and with its associated motor nerves.

149. In comparing the nervous system of Insects with that of the higher Mollusca, it will be seen that they differ more in the arrangement and in the relative proportions of their parts, than in their absolute character. In both there is a cephalic division of the ganglionic centres, in which sensibility and voluntary power appear to reside more particularly, if not entirely. In both there is a division specially appropriated to the locomotive apparatus, differing only in the multiplication of the centres in Insects, conformably with the arrangement of the members they supply; and sometimes consolidated to nearly the same degree. In both, also, we find a division appropriated to the respiratory apparatus, in which there is a corresponding multiplicity of centres in the Articulata, in harmony with the universal distribution of their tracheal system. And in both, as we shall now see, there is a separate system of nerves, distributed to the alimentary apparatus, and supplying the organs of mastication (with the salivary glands), of deglutition, and of digestion.

150. Of the *stomato-gastric* system, some traces may be found in nearly all the Articulated classes. Thus, in the Leech, we find a minute ganglion existing at the base of each of the three teeth which form the mouth; these ganglia are connected together, and, to the cephalic, by slender filaments; and they seem also to be in connection with other filaments, which may be traced on the alimentary canal. As a specimen of its highly developed form, we shall describe that of the *Gryllotalpa vulgaris* (common Mole-Cricket). Here we find it consisting of two divisions; one placed on the median line, which may hence be called the *median* system; the other running on each side at some little distance, and hence called the *lateral* system. The Median system appears to originate in a small ganglion, situated anteriorly and inferiorly to the cephalic mass, with which it communicates by a connecting branch on each side. From this ganglion, nerves proceed to the walls of the buccal cavity, the mandibles, &c. Its principal trunk, however, (the *recurrent* of authors) is sent backwards beneath the pharynx. The ramifications of this are distributed along the œsophageal tube and dorsal vessel; whilst the trunk passes downwards to the stomach, where its branches inosculate with those supplied by the lateral system, and seem to assist in forming a pair of small ganglia, from which most of the visceral nerves radiate. The ganglia of the Lateral system are two on each side, lying behind and beneath the cephalic masses. The anterior pair are the largest, and meet on the median line, just behind the cephalic ganglia, with which they communicate. Posteriorly to these lie the second pair, which are in connection with them. Two cords pass backwards on

each side, one derived from the anterior, the other from the posterior, of these ganglia. They run along the sides of the œsophagus and dorsal vessel; and, after inosculating with the branches of the central system, enter the two cœliac ganglia, from which branches radiate to the abdominal viscera.

151. This system of ganglia and nerves has an evident affinity with the *Sympathetic* system of Vertebrata, as well as with some parts of the Cerebro-spinal system, more especially with the par vagum. It is to be remembered that the pneumogastric nerve of Vertebrata is distributed to three separate systems—the respiratory, the circulating, and the digestive. As we know that the ultimate fibrils of nerves never anastomose, there can be no doubt that these branches might be separately traced backwards into their ganglionic centres; and they may thus be regarded as *functionally* three distinct nerves. There is no difficulty, then, in understanding that the respiratory system of Insects and other Invertebrata may be analogous with the pneumonic portion of the par vagum, although it bears no relation with the cardiac and gastric divisions of the nerve. To the latter divisions the analogy of the recurrent nerve becomes sufficiently plain, when we look at its distribution upon the dorsal vessel, œsophagus, and stomach; but its commencement in the anterior ganglion, which also supplies the mouth and pharynx, might seem to place it on a different footing, until we have determined the true analogy of this last centre. It may be inferred from its situation, and from the distribution of its nerves, that this anterior is analogous both to the labial and pharyngeal ganglia of the higher Mollusca. These appear to form a division of the nervous system, by which the actions *immediately* concerned in the prehension of food are performed, almost as independently of the cephalic ganglia as are those of respiration. There is evidently, however, a greater tendency towards the union of *these* centres with the œsophageal collar, than of those presiding over the respiratory function, which is more independent of the will.

152. The division of the nervous system of Vertebrata with which this stomato-gastric system corresponds, is a question of more apparent difficulty; but, if we bring into comparison not only the highest but the lowest forms of the cerebro-spinal apparatus, the chief difficulties will be removed. The analogies drawn from the distribution of the nervous branches would lead us to infer, that the *third* division of the fifth pair (including its sensory and motor origins), the glosso-pharyngeal, and the gastric portion of the par vagum, would most nearly represent it. Now, when the fifth pair is traced back to its true origin, it is found to be not a cerebral but a spinal nerve; and it is then seen to arise from the medulla oblongata, in such close approximation with the par vagum and glosso-pharyngeal, as to show that, if this portion of the nervous centres were isolated from the rest, the nerves which proceed from it would form, anatomically as well as functionally, a natural group. The fifth pair, like other spinal nerves, may act in a simply reflex character; although, in Man, it is usually under the dominion of the will. In the lower animals we find these reflex actions bearing a much larger proportion to the voluntary, than in Man; and even in him we not unfrequently meet with cases in which the functions of the cerebral hemispheres seem suspended, whilst those of the spinal cord are unimpaired; so that the prehension of food by the lips may take place without any effort of the will. This has been observed in acephalous fœtuses, in puppies from which the brain has been removed, and in profound apoplexy. Further, the connection between the fifth pair and par vagum is very intimate in Fishes, the class which approaches nearest in the character of its nervous system to

the Vertebrata. We may reasonably infer, then, that the anterior ganglion is the principal centre of the reflex actions of the nerves, which correspond to the third branch of the fifth pair, to the glosso-pharyngeal, and to the gastric portion of the par vagum, in Vertebrata; whilst the branches which connect them with the cephalic ganglia bring these nerves more or less under the influence of the latter.

153. The *lateral* ganglia seem more analogous to the centres of the sympathetic system in Vertebrata; especially in the connection of their branches with all the other systems of nerves; and in the share which they have in the formation of the cœliac ganglia. This view of the relative functions of these two divisions of the stomato-gastric system, is strengthened by the fact, that the connection between the Sympathetic system of Fishes and the par vagum is much more intimate than in the higher Vertebrata; although, even in the latter, as will be shown hereafter, it is by no means so slight as it appears.*

154. Upon taking a general review of the facts which have been stated, and of the inferences which have been erected upon them, we perceive that between the strictly sensorial functions of the nervous system, and those operations in which its *internuncial* character only is employed, a tolerably distinct line of demarcation may generally be drawn. We have hitherto viewed this apparatus under two aspects:—1. As the instrument of the mind, by which it acquires a knowledge of the external world through the medium of sensation, and operates upon it by an exercise of volition. 2. As the means by which various movements are excited in the bodily structure, which are immediately necessary to the performance of the organic functions, and to its protection from injury. To these actions the general term *instinctive* may be given; that term being understood to imply the performance of a motion, or series of motions, *in direct respondence* to external impressions, *without the intervention of the will*, without any designed adaptation to purpose on the part of the animal, and often without its consciousness being necessarily affected. The first of these objects appears to be answered, chiefly if not entirely, by the cephalic ganglia and the nerves proceeding from them. The second is carried into effect by the ganglia connected with each organ, or series of organs, whose movements are thus excited. We have seen, that, however small is the bulk of the cephalic ganglia compared with the sum of the other masses, these send nerves to every part of the body supplied by the latter; for the purpose, it would seem, of controlling, harmonizing, or antagonizing their actions. These nerves proceed as connecting trunks from the cephalic ganglia to the other centres; and then divide into filaments, which unite with those proceeding from them to the several organs. Each organ, therefore, receives four sets of fibres; an *afferent* and *efferent* set, which connect it with the *cerebral* ganglia, and are the channels of sensation, and of the influence of the will; and an *afferent* and *efferent* set, which connect it with *its own* peculiar ganglion, and serve to convey the stimulus of impressions which produce motions by reflected influence. In proportion as the special sensory organs

* The view given above of the comparative structure and offices of the Nervous System in the Invertebrated animals, is chiefly abridged from the Author's Prize Thesis on this subject, in which additional details will be found, as well as many other illustrative figures and references to authorities. He has there, also, discussed the physiological explanation usually given of the double nervous cord of the Articulata, and having shown that it is neither consistent with itself, nor capable of being applied to the other Invertebrata, he has deemed it unnecessary to complicate the present sketch by introducing it.

are developed, and the animal is less completely governed by *mere* instinct, we find the cerebral ganglia and system of nerves more predominant.*

155. We observe among the Articulata the greatest perfection of instinctive movements anywhere exhibited. In these movements there is a most remarkable adaptation of means to ends; as in the construction of habitations by various Insects, and especially by the social Hymenoptera. But few persons will maintain that this adaptation is performed by the mind of the animal; since, on this supposition, every Bee solves a problem which has afforded scope for the laborious inquiries of the acutest human mathematician. The adaptation is in the original construction of a nervous system, which should occasion particular movements to be performed under particular external conditions; and the constancy with which these are performed by different individuals of the same species, when placed in the same conditions, leads at once to the belief, that they must be independent of any operations so variable as those of judgment and voluntary exertion. On the other hand, in the Vertebrata, we find the purely instinctive movements forming a smaller proportion of the whole actions, and brought under a more complete subjection to the sensori volitional system. This is evident from the greater variety which the actions exhibit; from the mode in which they

* {The view here taken by the Author of the respective functions of the ganglionic and non-ganglionic tracts in the Articulata—that the ganglionic portion is the centre of reflex action, and the non-ganglionic the channel of sensori-volitional action, of which the cerebral ganglia are the real centres—has received additional proof from the observations of Prof. OWEN. The following are Mr. Owen's remarks on this subject, as reported in the Medical Times, (June 25th, 1842.) "We have before us two opposite conditions of a large and important part of the trunk of two nearly allied and similarly organized crustacea. In one, the lobster, the post-abdomen is encased in a series of calcareous rings, forming a hard and insensible chain armour. But in the same degree as sensibility is lost the muscular power is increased; a great proportion of the contractile fibre is concentrated in the tail of the lobster, which forms its most powerful and almost exclusive organ of swimming. In the pagurus (hermit-crab), on the other hand, the muscular system is almost abrogated in the long post-abdomen, for this in fact takes no share in the locomotive functions of the body. It is occupied by part of the alimentary canal, and by glandular organs; the external integument has no part of its sensibility destroyed by the interposition of calcareous particles, but retains the necessary faculty of appreciating the smooth and unirritating condition of the interior surface of the deserted shell which it chooses for its abode; nay more, minute acetabula are developed in groups upon this sensitive integument; delicate ciliated processes are also attached to it, to which the eggs adhere in clusters, during their incubation in the female. The muscular system is reduced to a few minute fasciculi of fibres, regulating the action of the terminal claspers. If, as has been conjectured, the ganglionic enlargements of the abdominal cords monopolize the sensorial functions, and the non-ganglionic tracts the motor powers, we ought to have found no ganglia in the tail, which is constructed for motion exclusively; whilst in the tail, which is almost as exclusively sensitive, the ganglia ought to have been large and numerous. The contrary, however, is the fact. Six well-developed ganglia distribute nerves to the muscular fibres of the lobster's tail; non-ganglionic columns supply the sensitive tail of the hermit-crab, the only ganglion in which is the small terminal one, that seems to have been called into existence solely to regulate the actions of the muscles of the organ of adhesion. . . . . Admitting from analogy that the supra-œsophageal ganglion is that in which true sensation and volition reside, then those nervous filaments, which are exclusively connected therewith, and some of which would seem to extend the whole length of the animal along the dorsal aspect of the ganglionic columns, would form with their ganglionic centre the true sensori-volitional system; whilst any other ganglia superadded to the abdominal columns, with the nervous filaments terminating in or originating from them, would constitute the system for the automatic reception and reflection of stimuli. In these views I coincide with the ingenious physiologist Dr. Carpenter, and shall feel happy if their accuracy and soundness have received any additional proof from the facts of comparative anatomy, now for the first time, I believe, brought to bear upon this interesting problem."—C.}

are adapted to peculiar circumstances; from the degree in which they may be modified by education; and from various other indications of a superior kind of intelligence. At last, in Man, those instinctive movements which are not immediately requisite (like those of respiration) for the maintenance of the organic functions, are placed under the control of the will. This is especially true of the locomotive organs, whose reflex actions are entirely guided by the will, being only distinguishable when, from peculiar states of the system, the immediate influence of the brain upon them is suspended.

156. There is a *third* aspect, however, under which we are to consider the Nervous System; and this becomes more important in the highest division of the Animal kingdom, on which we are now about to dwell. We have hitherto spoken only of its influence on the contractile properties of the tissues to which it is distributed. It has, however, an important and direct connection with the purely organic functions of Nutrition and Secretion; and we shall see reason to regard it as the means, not only of placing the *animal* in relation with the external world, but of harmonizing and controlling the organic changes taking place in its own structure, and of bringing these under the influence of particular mental conditions. It is the opinion of many, that all the organic functions are *dependent* upon the innervation supplied to them by the system of nerves, which has been termed *Sympathetic* or *visceral*. It is incumbent, however, on those who uphold the necessity of this nervous power, to prove it definitively, since all analogy leads to an opposite conclusion. We may regard the capability of separating a particular secretion from the blood, as a peculiar property inherent in the glandular membrane, just as contractility is the inherent property of muscular fibre. As the peculiar arrangement of the excitable and contractile tissues in animals requires a nervous system to act as a conductor between them, and to blend their actions, so may the complicated organic functions of Animals require to be harmonized and kept in sympathy with each other, by some mode of communication more direct and certain than that afforded by the circulating system, which is their bond of union in Plants. We have seen, in the foregoing sketch, that the visceral system does not exist in a distinct form in the lower classes of Invertebrated animals; and also that the nervous system of these classes cannot, as a whole, be compared with it, although it may be regarded as containing some rudiments of it. As the divisions of this system become more evident, however, and the organic functions more complicated, some appearance of a separate sympathetic system presents itself; but this is never so distinct as in Vertebrata. Hence it may fairly be inferred that,—as the Sympathetic system is *not* developed in proportion to the predominant activity of the functions of organic life (which is so remarkable in the Mollusca when contrasted with the Articulata), but in proportion to the development of the higher divisions of the nervous system,—its office is not to contribute to these functions any thing essential to their performance, but rather to exercise that general control over them, which becomes necessary according as they are more independent of one another, and to bring them into relation with the system of Animal life.

Nervous System of Vertebrata.

157. When we direct our attention to the Nervous System of the Vertebrated classes, we are immediately struck by two remarkable differences which its condition presents, from that under which we have seen it to exist in the Invertebrata. In the latter it has seemed but a mere appendage to

the rest of the organism,—a mechanism superadded for the purpose of bringing its various parts into more advantageous relation. On the other hand, in the Vertebrata the whole structure appears subservient to it, and designed but to carry its purposes into operation. Again, in the Invertebrata, we do not find any special adaptation of the organs of support for the protection of the nervous system. It is either enclosed, with the other soft parts of the body, in one general hard tegumentary envelope, as in the Echinodermata and Articulata; or it receives a still more imperfect protection, as in the Mollusca. In the latter, the naked species are destitute of any means of passive resistance, and the nervous system shares the general exposed condition of the whole body; and it is not a little remarkable that, in the testaceous kinds, the portion of the body containing the nervous centres should be protruded beyond the shell, whilst the principal viscera are retained within it. Now, in the Vertebrata, we find a special and complex bony apparatus, adapted in the most perfect manner for the protection of the nervous system; and it is, in fact, the possession of a jointed spinal column, and of its cranial expansion, which best characterizes the group.

158. When we look more particularly at the nervous centres themselves, we perceive that they combine the general characters of those of the Articulata with those of the Mollusca. In the former, the power of active locomotion seems the chief object to be attained; and the predominant part of the apparatus is evidently the series of ganglia connected with the locomotive organs. The sensory ganglia appear subservient to these, both in size and function. On the other hand, in the Mollusca the sensory ganglia predominate; and under their function, which is to direct these walking stomachs to their food, the control of the locomotive apparatus seems to be placed. Now, in the Vertebrata we have the locomotive powers of the Articulata (reduced, however, in activity), united with the complex nutritive system of the Mollusca; and we find this combination manifested, not only in the organs themselves, but in the Nervous System, which stands in so close a relation with them. The Spinal Cord of Vertebrata is evidently the analogue of the ventral columns of Articulata. It is a continuous ganglion, containing two portions as distinct as the two tracts in the Articulata;—a *fibrous* structure, which is continuous between the Brain and the spinal nerves, and thus resembles the white tract in Insects;—and a *ganglionic* portion, principally composed of grey matter. In this grey matter, as in the ventral ganglia of Insects, a part of the roots of the spinal nerves are lost; whilst others may be traced to the brain. At the upper extremity of the Spinal cord (commonly termed the *Medulla Oblongata*), we find the ganglia and nerves of special sensation; and the organs which these supply are placed in immediate proximity with the entrance to the alimentary canal, and hold the same relation to it as in the Mollusca. But in addition to these, we find two ganglionic masses in all Vertebrata, to which we have no distinct analogue in the lower classes—the Cerebral ganglia, and the Cerebellum. With the development of the former of these, the perfection of the reasoning powers appears to hold a close relation; that of the latter seems connected with the necessity which exists for the adjustment and combination of the locomotive powers, when the variety of movements performed by the animal is great, and the harmony required among them is more perfect. Upon these points, however, we shall hereafter dwell.

159. The Visceral system of nerves now assumes a more distinct form. It does not share the protection of the Spinal column; but its ganglia lie for the most part in the general cavity of the trunk. The connections of the Cerebro-Spinal and Sympathetic systems may be best studied in the trunk;

since the regularity of the distribution of the spinal nerves prevents the existence of that doubt regarding the nature of the communication, which obscures the relation of the cranial nerves with the sympathetic. The visceral ganglia—namely, the cardiac and semilunar—may probably be regarded as the true centres of the Nervous System of Organic life; whilst the chain of ganglia, which lie along the spine, are intermediate between these and the cerebro-spinal system. When the filaments connecting these ganglia with the roots of the spinal nerves are closely examined, they are found to contain both kinds of fibres; and they can no more, therefore, be regarded as the *roots* by which the sympathetic system arises from the cerebro-spinal (as they were formerly described), than as the roots by which the latter originates from the former. The white tubular fibres which these filaments contain, are found, upon close examination, to be derived from both roots of the spinal nerves, and not from the posterior only, as some have supposed. The quantity of white fibres in the nerves proceeding from this lateral chain of ganglia, is much greater than that contained in the nerves of the solar plexus; and it is confirmatory of the idea just stated—that the visceral ganglia are the true centres of the sympathetic system—to find that the nerves proceeding from them are almost entirely composed of the fibres characteristic of this system. A few grey fibres may be found in almost all the Cerebro-spinal nerves; they are particularly abundant, however, in the first division of the Fifth pair. It would seem that only a part of these are derived immediately from the sympathetic nerve; and that the remainder may be traced into the grey matter of the ganglia, formed on the posterior roots of the spinal nerves and on the larger root of the fifth pair. As this grey matter consists of nucleated globules, like those which are found in the centres of the Sympathetic system, it may be surmised that this series of ganglia also may be regarded as belonging to the sympathetic system, and as having the same relation to the grey fibres contained in the cerebro-spinal nerves, as that which the semilunar ganglia have to the nerves of the solar plexus.

160. The branches proceeding from the Semilunar ganglia are distributed upon the abdominal viscera; and those of the Cardiac ganglia upon the heart and the vessels proceeding from it. The latter seem to accompany the arterial trunks through their whole course, ramifying minutely upon their surface; and it can scarcely be doubted that they exercise an important influence over their functions. What the nature of that influence is, however, will be a subject for future inquiry. It is so evidently connected with the operations of nutrition, secretion, &c., that the designation of "nervous system of organic life," as applied to this system, does not seem objectionable, provided that we do not understand it as denoting the *dependence* of these functions upon it. Even in Vertebrata, however, we do not always find the visceral system distinct from the cerebro-spinal. In the Cyclostome Fishes, the par vagum supplies the intestinal canal along its whole length, as well as the heart; and no appearance of a distinct sympathetic can be discovered. In Serpents, again, the lower part of the alimentary canal is supplied from the spinal cord, and the upper part by the par vagum; and though the lateral cords of the sympathetic may be traced, they are almost destitute of ganglia. Even in the highest Vertebrata, some of the glands, of which the secretion is most directly influenced by the condition of the mind, are supplied with most of their nerves from the cerebro-spinal system; thus, the lachrymal and sublingual glands receive large branches from the fifth pair, and the mammary glands from the intercostal nerves. It may therefore be regarded as not improbable, that the organic fibres contained in these nerves,

and principally derived from the ganglia at their roots, are the most direct channels through which the processes of nutrition and secretion are influenced by mental emotions; and that the office of the distinct visceral system is rather to bring these functional changes into harmony with each other.

161. The Spinal Cord, with its encephalic continuation—the Medulla Oblongata,—may be regarded as constituting the essential part of the nervous system of Vertebrata. Although the Cerebral Hemispheres in Man bear so large a proportion to it in size, that the Spinal Cord seems but a mere appendage to them, the case is reversed when we look at the other extremity of the scale;—the Cerebral Hemispheres in many Fishes being but ganglionic protuberances from the Medulla Oblongata. Moreover, the fact that animals are capable of living without the brain, whilst they at once die if deprived of the spinal cord, sufficiently demonstrates this. The spinal cord, then, when viewed in relation to the nervous system of the Invertebrata, may be regarded as including their respiratory, stomato-gastric, and pedal ganglia. That these should be associated together can scarcely be considered remarkable. It is obviously convenient that they should all be enclosed in the bony sheath provided for their protection, and their closer relation favours that sympathy of action, which is so important in animals of such complex structure and mutually dependent functions, as the higher Vertebrata. An animal either congenitally or experimentally deprived of its cerebral hemispheres, is very much in the condition of one of the Acephalous Mollusca. It can perform those respiratory movements on which depends the maintenance of its circulation, and consequently its whole organic life, it can swallow food brought within its reach, and it can, in some degree, exert its locomotive powers to obtain it; but it is unconscious of the direction in which these can be best employed, and is dependent upon the supplies of food that come within its grasp. The Acephalous Mollusca are so organized, that they find support from the particles brought in by their respiratory current; but the more highly organized Vertebrata are not capable of so existing, and they must have their food provided for them by an exertion of the mental powers. So long as an acephalous Vertebrate animal is duly supplied with its requisite food, so long may it continue to exist; and thus it is seen that the operations of the brain are rather connected with the *intelligence* than with the blind undesigning *instinct* of the animal.

162. It is only in the Vertebrata that the difference between the *afferent* and *efferent* fibres of the nerves has been satisfactorily determined. The merit of this discovery is almost entirely due to Sir C. Bell. He was led to it by a chain of reasoning of a highly philosophical character; and though his first experiments on the spinal nerves were not satisfactory, he virtually determined the respective functions of their two roots, by experiments and pathological observations upon the cranial nerves, before any other physiologist came into the field.* Subsequently his general views were confirmed by the very decided experiments of Müller; but, until very recently, some obscurity hung over a portion of the phenomena. It was from the first maintained by Magendie, and has been subsequently asserted by other physiologists, that the anterior and posterior roots of the nerves were both concerned in the reception of sensations and in the production of motions; for that, when the anterior roots were touched, the animal gave signs of pain, at the same time that convulsive movements were performed; and that, on touching the posterior roots, not only the sensibility of the animal seemed to be affected, but muscular motions were excited. These

* See British and Foreign Medical Review, Vol. ix. p. 140, &c.

physiologists were not willing, therefore, to admit more, than that the anterior roots were especially motor, and the posterior especially sensory. But the recently-attained knowledge of the reflex function of the spinal cord enables the latter portion of these phenomena to be easily explained. The motions excited by irritating the posterior root are entirely dependent upon its connection with the spinal cord, and upon the integrity of the anterior roots and of the trunks into which they enter; whilst they are not checked by the separation of the posterior roots from the peripheral portion of the trunk. It is evident, therefore, that excitation of the posterior roots does not act immediately upon the muscles through the trunk of the nerve, which they contribute to form; but that it excites a motor impulse in the Spinal Cord, which is propagated through the anterior roots to the periphery of the system. The converse phenomenon, the apparent sensibility of the anterior roots, has been still more recently explained by the experiments of Dr. Kronenberg,* who has satisfactortly proved that it is dependent upon a branch of the posterior root passing into the anterior root at their point of inosculation, and then directing itself towards the centre; for it was found that the sensibility of the anterior roots was not diminished by the separation of them from the spinal cord, whilst it was entirely destroyed by division of the posterior roots; thus proving that the latter constituted the channel through which the impression was conveyed.

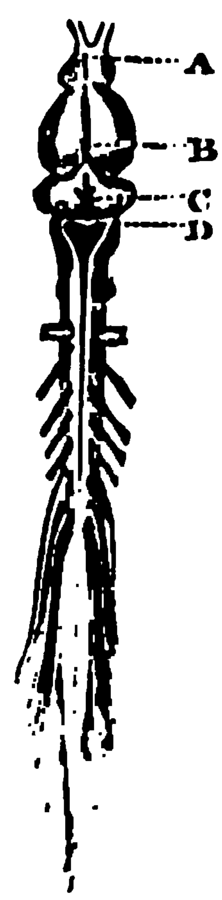
163. On the other hand, the distinctness of the system of nerves concerned in the simply reflex actions, from those which minister to sensation and volition by their connection with the brain, is by no means so obvious as in the Invertebrated classes. When first pointed out by Dr. Marshall Hall, who had grounded his opinion more upon physiological phenomena than upon anatomical facts, the statement did not command general assent; since, while the phenomena were admitted, the inferences drawn from them by him were not regarded as necessary results. When, however, the anatomy of the nervous centres in Vertebrata was more closely inquired into (by Mr. Grainger, who had been partly anticipated by Bellingeri), it was found to present certain phenomena which might be regarded as supporting Dr. M. Hall's views; and when the inquiry was extended to the Invertebrated classes, the confirmation was found to be still more decisive. In our previous sketch these doctrines have been treated as established; since they have been found not only to correspond with the facts disclosed by anatomical research, but to be required by them. We shall now apply them to the nervous apparatus of the Vertebrata.

164. The Spinal Cord consists of two lateral halves; these are partially separated, in the higher classes, by the superficial anterior and posterior fissures; and in Fishes by an internal canal, which is continuous with the fourth ventricle. This canal is evidently the indication of that complete separation of the two columns, which exists in the lower Articulata; and the fourth ventricle, which, in many fishes, remains unclosed (the cerebellum not being sufficiently developed to overlap it), corresponds with the passage between the cords uniting the cephalic ganglia with the first sub-œsophageal, through which the œsophagus passed in all the Invertebrata. The two lateral halves have little connection with each other in Fishes, and the pyramidal bodies at their apex scarcely decussate; but, in ascending towards the higher classes, the communication between the two sides is more intimate, and a larger proportion of the pyramidal fibres crosses to the opposite sides. In all the Vertebrata, the true Spinal Cord

* Müller's Archiv. 1839, Heft v.; and Brit. and For. Med. Rev., Vol. ix. p. 547.

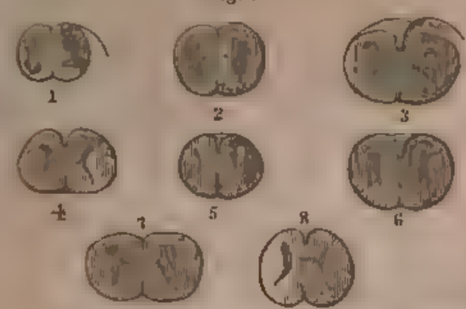
contains grey substance, or something equivalent to it; thus possessing the character of a continuous ganglion. The proportion of the vertebral column which this ganglionic portion occupies, is, however, extremely variable; depending principally on the position of the chief organs of locomotion. Thus, in the Eel, and other Vermiform Fishes, it is continued through the whole Spinal canal; whilst in the Lophius and Tetraodon, whose body is less prolonged, and more dependent for its movements upon the anterior extremities, the true Spinal Cord scarcely passes out of the cranium. The quantity of grey matter is nearly uniform in every part of the cord, where there is no great diversity in the functions of the nerves which originate from each portion. In most Fishes, for example, the body is propelled through the water more by the lateral action of the flattened trunk, whose surface is extended by the dorsal and caudal fins erected upon prolongations of its vertebræ, than by the movements of its extremities, which serve principally to guide it. Hence we usually find the amount of grey matter varying but little in different parts of the cord. But in the Flying-fish, and others whose pectoral fins are unusually powerful, a distinct ganglionic enlargement of the cord takes place where the nerves are given off. In Serpents, again, the spinal cord is nearly uniform throughout its entire length; whilst in Amphibia it is so during the Tadpole condition, but presents enlargements corresponding to the anterior and posterior extremities, when these are developed; at the same time becoming much shortened, as the tail is less important to locomotion, or is altogether atrophied. In Birds, the ganglionic enlargements are generally very perceptible, and bear a close relation in size with the development of the locomotive organs with which they are connected. Thus, in Birds of active flight and short powerless legs, the anterior enlargement is the principal; but in those which are more adapted to run on land than to wing their way through the air, such as the whole tribe of Struthious birds, the size of the posterior enlargement is very remarkable. Hence we have a right to infer, that the increase in the quantity of grey matter in the cord has some connection with the amount of power to be supplied; and this exactly corresponds with what has been observed in the Articulated classes, and especially in watching the metamorphoses of Insects. In Birds and Mammalia, however, the whole amount of the grey matter in the spinal cord does not bear so large a proportion to the bulk of the nerves proceeding from it, as in the lower Vertebrata; and the reason of this seems obvious. The actions of the locomotive organs are less and less of a reflex character, and are more directly excited by the will, and consequently by the brain, than in the inferior tribes; and just in proportion, therefore, to the development of the Brain will it become the centre of all the actions performed by the animal, and the Spinal Cord a mere appendage to it. S[illegible] the Mammalia, even in Man, [illegible] we find these ganglionic enlargements of the spinal cord; and in Man it is the posterior (or rather the inferior) one which contains the largest quantity of grey matter. In the cord of [illegible]

Fig. 13.



Nervous Centres in Frog: A, olfactive ganglia; B, cerebral hemispheres; C, optic ganglia; D, cerebellum, so small as not to cover the 4th ventricle, or cavity left by the divergence of the columns of the Spinal Cord.

Fig. 14.



Transverse sections of human Spinal Cord at different points, showing proportional quantity and arrangement of grey and white matter at each, after Solly. 1, opposite 11th dorsal vertebra; 2, opposite 10th dorsal; 3, opposite 8th dorsal; 4, opposite 5th dorsal; 5, opposite 7th cervical; 6, opposite 4th cervical; 7, opposite 3d cervical; 8, section of medulla oblongata through centre of corpus olivare.

much more intimately united, than in the classes below; for not only is the central canal for the most part absent, but the two crescent-shaped plates of grey matter are united by a transverse lamella, which connects their centres like a commissure.

165. The Cord is traversed not only by the anterior and posterior fissures, but by two furrows on each side, marking out three columns upon it. We have, therefore, on each half of the cord, an anterior, middle or lateral, and posterior column. The points of the crescentic lamellæ of grey matter approach these furrows pretty closely; but elsewhere the grey matter is covered deeply by the fibrous columns. Each spinal nerve arises from two sets of roots. The anterior roots join the spinal cord near the anterior furrow; and the posterior near the posterior furrow. Respecting their intimate connection with the principal divisions of the cord, however, a considerable diversity exists among the statements of anatomists. In the first place, with regard to their connection with the fibrous and cineritious structures, it may be stated, that a portion of the posterior set of roots unquestionably loses itself in the grey matter of the Spinal Cord; whilst of another portion, the fibres are continuous with those of the white columns. There is more difficulty, however, in tracing the anterior roots into the grey substance. Still, however, the connection has been made out, although not in the human subject, by Bellingeri and Grainger; and there is reason to believe, therefore, that it is constant, although not readily perceptible. Of the portions of the roots which are continuous with the fibrous columns, it is stated by Sir C. Bell that the anterior fasciculi pass to the anterior columns only, and that the posterior are restricted to the lateral columns. On the other hand, Mr. Grainger and Mr. Swan maintain that both sets are connected with the lateral columns only; the anterior and posterior lateral fissures definitely limiting the two roots. Perhaps both these statements are rather too exclusive. The anterior roots would seem to have a connection with both the anterior and lateral columns; and the posterior cannot be said to be restricted to the lateral column, some of their fibres entering the posterior division of the cord.

166. As the white or fibrous portion of the Spinal Cord is continuous with the medullary matter of the Brain, the roots of the nerves which enter it are in reality thus brought into connection with the Cerebral Hemispheres and Cerebellum; and the posterior division of these may, therefore, be regarded as conducting to the brain the impressions which there become sensations; whilst the anterior roots convey the motive influence, which has been propagated, by a voluntary impulse, down the tract of the Spinal Cord with which they are continuous. On the other hand, the termination of one portion of each set of roots in the grey matter of the Cord, completes the nervous circle required for the performance of reflex actions; and by this they would seem to take place in Vertebrated animals, just as

through one of the ganglia in the Articulata. It follows, then, on this view of the character of the Spinal Cord, that the continuity of the fibrous tracts is all that is required to convey the influence of the will to the parts below; whilst the completeness of the nervous circle is all that is necessary for the performance of reflex actions excited through it. This is found to be strictly true; the former having been observed in cases of disease, and the latter having been proved by experiment. As far as simple reflex actions are concerned, there is as much segmental independence in Vertebrata as in the Articulata; but these actions seldom have so completely the character of adaptation, and are of a more irregular and convulsive nature. Still, however, there is an essential correspondence between them; and we may, therefore, regard the distinction between the reflex and voluntary movements as the same in each group; the former predominating in Articulata; the latter in Vertebrata. On this view, then, each spinal nerve contains at least four sets of fibres.

I. A sensory bundle passing upwards to the brain.

II. A motor set, conveying the influence of volition downwards from the brain.

III. Excitor or centripetal fibres, terminating in the true spinal cord or ganglion, and conveying impressions to it.

IV. A motor or centrifugal set, arising from the same ganglionic centre, and conveying the motor impulse reflected from it to the muscles.

Of these the first and third are united in the posterior or *afferent* roots; the second and fourth in the anterior or *efferent* roots.

167. It is difficult to trace the course of the fibres within the Spinal Cord; and some recent experiments by Valentin appear to prove, that Sir C. Bell was not altogether correct in his idea, that the functions of the columns of the cord are respectively similar to those of the roots connected with them. Cases, indeed, are of no unfrequent occurrence, in which a portion of one of the columns has been almost entirely destroyed by injury or disease, without any corresponding loss of the function attributed to it. Such cases have kept alive, in the minds of many eminent practical men, a considerable distrust of the accuracy of Sir C. Bell's conclusions. We have seen that, in regard to the roots of the nerves, his first statements have been confirmed, and rendered more precise, by subsequent researches; but it is not so in regard to the functions of the anterior and posterior divisions of the Spinal Cord. Bellingeri was led, by experiments on the spinal cord, to the conclusion, that the anterior roots of the nerves were for the flexion of the various articulations, and the posterior for their extension. He also was wrong, in extending an inference, founded on experiments on the Cord, to the roots of the nerves. The recent experiments of Valentin, whilst they fully confirm Sir C. Bell's determination of the functions of the roots of the nerves, coincide, to no small degree, with Bellingeri's opinion in regard to the offices of the anterior and posterior divisions of the cord. He obtained reason to believe that, in the Frog, neither the superior nor inferior strands of the cord (posterior and anterior columns in Man) solely possess motor functions: but he found that, when the former were irritated, sensations predominated; and when the latter, motions were chiefly excited. He further states that, if the superior strand (*posterior column*) be irritated at the point at which the nerves of either extremity are given off, that extremity is *extended;* and that if the inferior strand (*anterior* column) be irritated, the extremity is *flexed.* At their entrance into the spinal cord, therefore, it would appear that the motor fibres of the extensors pass towards the superior stratum (posterior column in Man),

whilst those of the flexors are continuous with the inferior stratum (anterior column); their course being more altered, however, when they are examined far from the point of issue. This doctrine was confirmed by experiments on Mammalia; and is borne out (according to Valentin) by pathological phenomena observed in Man. According to this eminent physiologist, also, relaxation of the sphincters is analogous to the extended state of the extremities; and he has noticed a manifest relaxation of the sphincter ani in the frog, when the superior part of the spinal cord was irritated, so as to produce extension of the limbs. These statements are entitled to considerable weight, on account of the quarter from which they come; but they are not, perhaps, to be received altogether without hesitation, until confirmed by other physiologists, especially whilst the phenomena of reflex action are still so imperfectly known. For it is quite possible that, whilst stimulation of the anterior part of the cord may excite direct motions of flexion in preference to those of extension, the movements of extension produced by stimulating the posterior column may be of a reflex character.

168. There is no reason to believe, that the functions of the Spinal Cord are essentially different along its whole length. Everywhere it appears to consist of a ganglionic centre, supplying nerves to its particular segment; and of connecting fibres, by which the nerves proceeding from any one division are brought into relation with distant portions of the organ, and with the large ganglionic masses at its anterior extremity. In this respect, then, it corresponds precisely with the double nervous cord of the Articulata; the only prominent difference between the two being, that in the former the ganglionic matter is continuous from one extremity of the organ to the other, whilst in the latter it is interrupted at intervals; and in the Mollusca the centres are still further separated from each other. The connection of the Spinal Cord with the large ganglia contained within the cavity of the cranium, is effected by means of processes from its superior extremity, the arrangement of which is somewhat complex. This portion of the cord, which also lies within the cavity of the cranium, has been termed the *Medulla Oblongata*. It has been supposed to be the peculiar seat of vitality; but the only real foundation of this idea is, that it is the great centre of the respiratory actions, on the continuance of which all the other functions are dependent. The Brain may be removed from above, and nearly the whole Spinal Cord from below, without an immediate check being put upon all the nervous phenomena of life. In this Medulla Oblongata, *four* different parts may be distinguished on each side;—1, The Anterior Pyramids, or *Corpora Pyramidalia;* 2, The Olivary bodies, or *Corpora Olivaria;* 3, The Restiform bodies, or *Corpora Restiformia*, otherwise called *Processus a Cerebello ad Medullam Oblongatam;* 4. The Posterior Pyramids, or *Corpora Pyramidalia Posteriora.* The connections of these with the Brain above, and with the Spinal Cord below, will be now traced.*

* Great diversities will be found in the accounts given of these connections by different authors; some of which are attributable to a variation in the use of terms, which must not pass unnoticed. By the majority of Anatomists, the name of Corpora Restiformia is given to the *Cerebellar* Columns; and this designation, therefore, it seems advisable to retain. Some, however, and amongst them Dr. J. Reid, in his late very excellent description of the Anatomy of the Medulla Oblongata (Edin. Med. & Surg. Journal, Jan. 1841), give the name to the columns that pass up from the posterior division of the spinal cord into the crus cerebri,—which are here called (after Sir C. Bell) the posterior pyramids; and apply the term Posterior Pyramids to the Cerebellar column. The truth is that, as Sir C. Bell has justly observed, *all* the

169. As our object, however, is rather Physiological than purely Anatomical, we shall commence with a description of the *motor* and *sensory* tracts, which may, according to Sir C. Bell,* be very distinctly separated in the Pons Varolii. The Pons has been very properly designated as the

Fig. 15.

Course of the Motor tract, after Sir C. Bell. A, A, fibres of the hemispheres, converging to form the anterior portion of the crus cerebri; B, the same tract where passing the crus cerebri; C, the right pyramidal body, a little above the point of decussation; D, the remaining part of the pons Varolii, a portion having been dissected off to expose B.—1, olfactory nerve, in outline; 2, union of optic nerves; 3, 3, motor oculi; 4, 4, patheticus; 5, 5, trigeminus; 6, 6, its muscular division, 7, 7, its sensory root; 8, origin of sensory root from the posterior part of the medulla oblongata; 9, abducens oculi; 10, auditory nerve; 11, facial nerve; 12, eighth pair; 13, hypoglossal; 14, spinal nerves; 15, spinal accessory of right side, separated from par vagum and glosso-pharyngeal.

tracts of fibrous matter connecting the Brain with the Spinal Cord, have a somewhat *pyramidal* form; and it might be added that all have something of a *restiform* or cord-like aspect.

* Philosophical Transactions, 1835.

great Commissure of the Cerebellum, enclosing the Crura Cerebri; and its transverse fibres not only *surround* the longitudinal bands which connect the Cerebrum with the Spinal Cord, but *pass through* them, so as in some degree to isolate the two lateral halves from one another, and to form a complete septum between the anterior and posterior portions of each. The *Motor* tract is brought into view by simply raising the superficial layer of the Pons, and tracing upwards and downwards the longitudinal fibres which then present themselves. It is then found, that these fibres may be traced *upwards* chiefly into the Corpora Striata, whence they radiate to the hemispheres; and *downwards*, chiefly into the Anterior Pyramids. From this tract arise *all the Motor nerves* usually reckoned as Cerebral; as will be seen in the accompanying Figure. The *Sensory* tract is displayed by opening the Medulla Oblongata on its posterior aspect; separating and turning aside the Restiform Columns, so as to bring into view the Posterior Pyramids, which lie on the outside of the calamus scriptorius. On tracing their fibres upwards, it is found that they form a part of the posterior layer of the Crura Cerebri, ultimately passing on to the Thalami Nervorum Opticorum, whence they radiate to the hemispheres. From this tract no motor nerves arise; but on tracing it downwards into the Spinal Cord, it is found that the *sensory* root of the fifth pair terminates in it, and that the posterior roots of the spinal nerves are evidently connected with its continuation. Also forming part of the posterior division of the crus cerebri, and separated from the anterior by the transverse septum, is a layer of fibres which ascends from the Olivary bodies, some of which terminate in the Corpora Quadrigemina.

Fig. 16.

Course of the Sensory tract, after Sir C. Bell. A, Pons Varolii; B, B, sensory tract separated; C, union and decussation of posterior columns; D, D, posterior roots of spinal nerves; E, sensory roots of fifth pair.

170. On tracing *upwards* the four divisions of the Medulla Oblongata, the following are found to be their chief connections with the brain. The fibres of the Anterior Pyramids for the most part enter the Crura Cerebri, passing through the Pons Varolii, and traversing the Optic Thalami (which, it must be carefully borne in mind by the Student, have *no real* connection with the Optic Nerves or with the sense of sight); after which they diverge and become intermingled with grey matter, thus forming the Corpora Striata, and finally radiate to the convolutions of the Cerebrum. The fibres of the Olivary body also pass into the Pons Varolii, and there divide into two bands, of which one proceeds upwards and forwards to join the Crus Cerebri, whilst the other passes upwards and backwards into the Corpora Quadrigemina. Of the true Restiform bodies, the fibres pass entirely into the Cerebellum. Finally, of the Posterior Pyramids, the fibres pass directly onwards through the Crura Cerebri into the Thalami, whence they radiate to the convolutions.

171. The *downward* course of these fibres into the Spinal Cord now remains to be traced; and their arrangement is by no means a simple one. The anterior pyramids decussate, as is well known, at their lower extremity; the principal part, but not the whole, of the fibres on each side passing over to the other. The *decussating* fibres pass *backwards* as well as downwards, and enter, not the anterior column of the spinal cord (as commonly stated), but the *middle* column. The smaller bundle of fibres, which do not decussate, passes downwards, along with those of the olivary bodies, to form the anterior column. The fibres descending from the Olivary bodies converge, as those of the pyramids pass backwards from between them, until they meet on the median line, forming the greater part of the *anterior* column. The fibres of the Posterior Pyramids are stated by Sir C. Bell to decussate like those of the anterior; they pass down chiefly into the posterior part of the *middle* column, forming part also of the posterior. The fibres of the Restiform, or Cerebellar columns,—which, like those of the Olivary columns, do not decussate,—mostly pass downwards into the posterior columns; but a band (which has been termed, from its curved aspect, the *arciform* layer) passes forwards into the interior columns.

172. The following tabular view may assist, better than any delineations could do, in the comprehension of this very intricate piece of Anatomy; the knowledge of which can be already applied to the explanation of many curious pathological phenomena, and cannot but assist in the elucidation of others whose rationale is as yet obscure.

SPINAL CORD.	MEDULLA OBLONGATA.	BRAIN.
Anterior Column	Arciform fibres of Cerebellar Columns	Cerebellum
	Olivary Columns	Corpora Quadrigemina
	Non-decussating portion of ant. pyramids	Corpora Striata
Middle Column	Decussating portion of Ant. Pyramids	
	Post. Pyramidal Columns (decussating)	
Posterior Column	Portion of Post. Pyramids (non-decussating?)	Thalami Optici
	Restiform Columns	Cerebellum

Functions of the Spinal Cord.

173. The functions of the Nervous System in Vertebrated Animals are so complex in their nature, and our means of analyzing them are so imperfect, that the inquiry is confessedly one of the greatest difficulty, and needs all the light which can be thrown upon it from any source. The great anato-

sion to our knowledge of them, which has been made within the last few years, chiefly by the labours of Sir C. Bell, and Dr. M. Hall, has so far changed the aspect of this department of Physiological Science, as to render it necessary for those who had previously studied it to begin *de novo*. This is especially the case in regard to the actions dependent on the Spinal Cord, which it seems desirable to consider in the first instance, in order that it may be clearly defined what the Brain does *not* do. By many, even in recent times, the Spinal Cord has been considered as a mere appendage to the Brain; but the phenomena of its independent action render such an idea quite inadmissible. These phenomena have been especially pointed out by Dr. M. Hall; and it is mainly owing to his arguments, that Physiologists are now for the most part agreed in the general fact,—that the Spinal Cord constitutes a distinct centre, or rather a collection of centres, of nervous influence, and that its operations are carried on through the nervous trunks with which it is connected. It is further generally admitted that its functions are independent of the will; and that they are in effect frequently opposed to those of the brain, which operates on the muscles either by a *volitional* or by an *emotional* impulse. And, lastly, its actions are always (except when excited by a physical irritation directly applied to itself) entirely of a *reflex* character: that is to say, the motor impulses which originate in it are not spontaneous, but result from the stimulus of impressions, conveyed to it by the afferent trunks, and operating upon it, to use the expression of Prochaska, according to certain "peculiar laws written, as it were, by nature on its medullary pulp." It is not, however, universally admitted that these actions are independent of *sensation;* and some eminent physiologists, among whom may be named Dr. Alison, still hold that the intervention of sensation is necessary,—in the case, at least, of the ordinary associated movements, which have definite ends in view, and follow one another in regular succession, as those of Respiration,—for an impression to give rise to that organic change in the spinal cord which shall terminate in a muscular motion.* It will be desirable, therefore, to consider the evidence upon which the statement rests, that reflex actions are independent of sensation, though ordinarily accompanied by it.

174. In the first place, then, it has long been well known that, in the Human being, the Spinal Cord does not itself possess in the remotest degree the power of communicating sensory impressions to the mind; since, when its lower portion has been severed from the brain by injury or disease, there is complete anæsthesia of all the parts of the body which derive their nerves exclusively from it. Hence it might be inferred, that, throughout the Vertebrated classes, the spinal cord is equally destitute of sensibility; and that whatever movements may be produced by stimuli acting through it, are the results of a physical, and not of a sensorial change. This inference, however, has been disputed; and, if unsupported by other evidence, it would not, perhaps, be entitled to rank as an ascertained truth. The very performance, by decapitated animals of inferior tribes, of actions which had not been witnessed in Man under similar circumstances, has been held to indicate, that the spinal cord in them had an endowment which his did not possess. The possibility of such an explanation—however unconformable to that analogy throughout organized nature which, the more it is studied, the more invariably does it guide to truth—could not be disproved. Whatever experiments on decapitated animals were appealed to in support of the doctrine that the brain is the only seat of sensibility, could be met by a sim-

* See Outlines of Physiology, 3d edit. p. 211.

ple denial that the spinal cord is everywhere as destitute of that endowment as it appears to be in Man. The cases of profound sleep and apoplexy might be appealed to, as examples of reflex action without consciousness; and these might be met by the assertion, that in such conditions sensations are felt, though they are not remembered. It is difficult, however, to apply such an explanation to the case of anencephalous human infants (in which all the ordinary reflex actions have been exhibited with an entire absence of the brain), without supposing that the Medulla Oblongata is the seat of a sensibility, which we know that the lower part of the Spinal Cord does not possess; and of this there is no evidence whatever.

175. Experiments on the lower animals, then, and observation of the phenomena manifested by apoplectic patients and anencephalous infants, *might* lead to the conclusion that the spinal cord does not possess sensibility, and that its reflex actions are independent of sensation. At this conclusion, Prochaska, Sir G. Blane, Flourens, and other physiologists, had arrived; but it was not until special attention was directed to the subject by Dr. M. Hall, that facts were obtained, by which a positive statement of it could be supported. For the question might have been continually asked,—If the spinal cord in Man is precisely analogous in function to that of the lower Vertebrata, why are not its reflex phenomena manifested, when a portion of it is severed from the rest by disease or injury? The answer to this question is twofold. In the first place, simple division of the cord with a sharp instrument leaves the separated portion in a state of much more complete integrity, and therefore in a state much more fit for the performance of its peculiar functions, than it ordinarily is after disease or violent injury: and as the former method of division is one which the physiologist is not likely to meet with in Man as a result of accident, and cannot experimentally put in practice, the cases in which reflex actions are manifested are likely to be comparatively few. But, secondly, a number of such instances *have* now been accumulated, sufficient to prove that the occurrence is by no means so rare as might have been supposed: and that nothing is required but patient observation, to throw great light on this interesting question from the phenomena of disease. A most valuable collection of such cases, occurring within his own experience, has been published by Dr. W. Budd;* and the leading facts observed by him will be now enumerated.

176. In the first case, paraplegia was the result of angular distortion of the spine in the dorsal region. The sensibility of the lower extremities was extremely feeble, and the power of voluntary motion was almost entirely lost. "When, however, any part of the skin is pinched or pricked, the limb that is thus acted on jumps with great vivacity: the toes are retracted towards the instep, the foot is raised on the heel, and the knee so flexed as to raise it off the bed: the limb is maintained in this state of tension for several seconds after the withdrawal of the stimulus, and then becomes suddenly relaxed." "In general, while one leg was convulsed, its fellow remained quiet, unless stimulus was applied to both at once." "In these instances, the pricking and pinching were perceived by the patient; but *much more violent* contractions are excited by a stimulus, *of whose presence he is unconscious.* When a feather is passed lightly over the skin in the hollow of the instep, as if to tickle, convulsions occur in the corresponding limb, much more vigorous than those induced by pinching or pricking: they succeed one another in a rapid series of jerks, which are repeated as long as the stimulus is maintained. "When any other part of the limb is [illegible]

* Medico-Chirurgical Transactions, vol. xx.

in the same way, the convulsions which ensue are very feeble, and much less powerful than those induced by pricking or pinching." "Convulsions, identical with those already described, are at all times excited by the acts of defecation and micturition. At these times, the convulsions are much more vigorous than under any other circumstances, insomuch that the patient has been obliged to resort to mechanical means to secure his person while engaged in these acts. During the act of expulsion, the convulsions succeed one another rapidly, the urine is discharged in interrupted jets, and the passage of the fæces suffers a like interruption." The convulsions are more vigorous the greater the accumulation of urine; and involuntary contractions occur whenever the bladder is distended, and also when the desire to relieve the rectum is manifested. "In all these circumstances, the convulsions are perfectly involuntary; and he is unable, by any effort of the will, to control or moderate them." The patient subsequently regained, in a gradual manner, both the sensibility of the lower extremities, and voluntary power over them; and as voluntary power increased, the susceptibility to involuntary movements, and the extent and power of these, diminished.

177. This case, then, exhibits an increased tendency to perform reflex actions, when the control of the brain was removed; it also shows that a slight impression upon the surface, of which the patient was not conscious, was more efficacious in exciting reflex movements, than were others more powerfully affecting the sensory organs. This is constantly observed in experiments upon the lower animals; and it harmonizes, also, with the important fact, that, when the *trunk* of an afferent nerve is pinched, pricked, or otherwise irritated, the reflex function will not be nearly so strongly excited, as when a gentler impression is made on a *surface* supplied by the branches of this nerve. The former produces *pain*, whilst the latter does not; the amount of sensation, therefore, does not at all correspond with the intensity of reflex action, but rather bears a converse relation to it. Mr. Grainger found that he could remove the entire hind leg of a Salamander with the scissors, without the creature moving, or giving any expression of suffering, if the spinal cord had been divided; yet that, by irritation of the foot, especially by heat, in an animal similarly circumstanced, violent convulsive actions in the leg and tail were excited.—It should be added that, in the foregoing case, the nutrition of the lower extremities was not impaired, as in most cases of paraplegia. The rationale of this occurrence, which is a phenomenon to be constantly observed when the reflex actions of the part remain entire, will be hereafter noticed (CHAP. v.).

178. In another case, the paralysis was more extensive, having been produced by an injury (resulting from a fall into the hold of a vessel) at the lower part of the neck. There was at first total loss of voluntary power over the lower extremities, trunk, and hands; slight remaining voluntary power in the wrists, rather more in the elbows, and still more in the shoulders. The intercostal muscles did not participate in the movements of respiration. The sensibility of the hands and feet was greatly impaired. There was retention of urine, and involuntary evacuation of the fæces. Recovery took place very gradually; and during its progress several remarkable phenomena of reflex action were observed. At first, tickling one sole excited to movement that limb only which was acted upon; afterwards, tickling either sole excited both legs, and on the 26th day, not only the lower extremities, but the trunk and upper extremities also. Irritating the soles, by tickling or otherwise, was at first the only, and always the most efficient method, by which convulsions could be excited. From the 26th to the 69th day, involuntary movements in all the palsied parts continued powerful and

extensive, and were excited by the following causes:—In the lower extremities only, by the passage of flatus from the bowels, or by the contact of a cold urinal with the penis; convulsions in the upper extremities and trunk, attended with sighing, by plucking the hair of the pubes. On the 41st day, a hot plate of metal was applied to the soles, and found a more powerful excitor of movement than any before tried. The movements continued as long as the hot plate was kept applied; but the same plate, at common temperature, excited no movements after the first contact. The contact was distinctly felt by the patient; but *no sensation of heat* was perceived by him, although the plate was applied hot enough to cause vesication. At three different intervals the patient took one-eighth of a grain of strychnia three times a day. Great increase of susceptibility to involuntary movements immediately followed, and they were excited by the slightest causes. No convulsions of the upper extremities could ever be produced, however, by irritating their integument; though, under the influence of strychnia, pulling the hair of the head, or tickling the chin, would produce violent spasmodic actions in them. Spontaneous convulsions of the palsied parts, which occurred at other times, were more frequent and more powerful after the use of strychnia. On the first return of voluntary power, the patient was enabled to restrain in some measure the excited movements; but this required a distinct effort of the will, and the first attempts to walk were curiously affected by the persistence of the susceptibility to excited involuntary movements. When he first attempted to stand, the knees immediately became forcibly bent under him; this action of the legs being excited by contact of the soles with the ground. On the 95th day this effect did not take place until the patient had made a few steps; the legs then had a tendency to bend up, a movement which he counteracted by rubbing the surface of the belly: this rubbing excited the extensors to action, and the legs became extended with a jerk. A few more steps were then made; the manœuvre repeated, and so on. This susceptibility to involuntary movements from impressions on the soles gradually diminished; and on the 141st day, the patient was able to walk about, supporting himself on the back of a chair which he pushed before him; but his gait was unsteady, and much resembled that of chorea. Sensation improved very slowly: it was on the 53d day that he first slightly perceived the heat of the metal plate.

179. This important case suggests many interesting reflections. Common sensation was not so completely abolished as in the former instance; but of the peculiar kind of impression, which was found most efficacious in exciting reflex movements, no consciousness whatever was experienced. Not less interesting was the circumstance, that convulsions could be readily excited by impressions on surfaces above the seat of injury: as, by pulling the hair of the scalp, a sudden noise, and so on. This proves two important points: first, that a lesion of the cord may be such as to intercept the transmission of voluntary influence, and yet may allow the transmission of that reflected from incident nerves. Secondly, that all influences from impressions on incident nerves are diffused through the cord; for, in the instance adduced, the reflected influence was undoubtedly not made to deviate into the cord by the morbid condition of that organ, but followed its natural course of diffusion, being rendered manifest in this case by the convulsions which were excited, in consequence of increased activity of the motor function of the cord.* It is further interesting to remark that in the foregoing case, the

* It is obvious, therefore, that when we consider the spinal cord as an organ com-

reflex actions were very feeble during the first seven days, in comparison with their subsequent energy; being limited to slight movements of the feet, which could not always be excited by tickling the soles. In another case of very similar character, it was three days after the accident, before any reflex actions could be produced. It is evident, then, that the spinal cord must have been in a state of concussion, which prevented the manifestation of its peculiar functions, so long as the effect lasted; and it is easy, therefore, to perceive that a still more severe shock might permanently destroy its power, so as to prevent the exhibition of any of the phenomena of reflex action.

180. It seems well established, then, by such cases, that the Spinal Cord, or small segments of it, may serve in Man as the centre of very energetic reflex actions, when the voluntary power exercised through the Brain over the muscular system is suspended or destroyed. And it is further evident, that these movements are produced by a mere physical change in the nervous centres; the consciousness of the individual not being affected in their performance, and sensation having therefore no necessary participation in them. The movements witnessed in the lower animals under the same circumstances being altogether of a similar character, there seems no good reason to attribute to the Spinal Cord in them an attribute of which it is certainly destitute in Man. There is no essential difference, either in structure, or in the nature of the actions performed by them, between the Spinal Cord and the Medulla Oblongata, which can warrant us in assigning to the latter a function that the former does not possess; and if the reflexions of the Spinal Cord do not involve sensation, there is good reason for concluding, that this change is not a necessary element in those of the Medulla Oblongata. It is perfectly true, that it always *accompanies* in us the greater number of actions, to which that division of the centre is subservient; for example, those of respiration and deglutition: and it is scarcely possible for such an accident to occur in the Human being, as the separation of the Medulla Oblongata from the brain, without the destruction of the independent functions of both. It is not likely that we can ever have the power of ascertaining, by the testimony of a patient so affected, that the respiratory movements are performed without the necessary intervention of sensation; as we have been able to do in regard to other reflex movements. But the general facts being, that there is no positive ground whatever for regarding any part of the spinal cord as a *sensorium* independent of the brain, and that the respiratory movements certainly correspond in all their conditions with the actions denominated reflex, there would seem no good reason for maintaining that sensation is an element to *their* production, whilst it is admitted to be not essential in the case of the less regular convulsive actions already described. The character of *adaptiveness* to a designed end, in regard to their combination and succession, which the movements of respiration and deglutition exhibit, is clearly no proof of their dependence on sensation; since an equally perfect adaptiveness is witnessed in the actions of the heart, alimentary

plete in itself, the terms *direct* and *retrograde* have no application; these being justly applied only when there is a determinate direction for the transmission of a change in the condition of the nerves: as when a sensory impression is propagated along an afferent trunk, or upwards to the brain in that part of the spinal cord which is a mere conductor; or when a motor impulse is propagated downwards from the brain through the conducting portion of the spinal cord, or by an efferent trunk. If, in either of these cases, the course of transmission could be reversed, it might be fairly said to be *retrograde;* but the true spinal cord is not a conducting organ, but a ganglionic centre for the reception and reflexion of impressions, which are diffused through it in all directions alike.

canal, &c. which are still further removed from the control of the will. And, further, it does not appear by any means evident, what end or purpose could be answered by the production of sensation as a part of the chain of phenomena of reflex action. The question is, are these movements guided in any way by the *mind;* or do they necessarily result from certain physical conditions of the nervous system? If their adaptiveness is the result of mental guidance, then not only sensation but judgment and volition must necessarily be involved; since it is impossible that sensation can guide to the choice of one out of many modes of action, without the exercise of these faculties. On the other hand, if it be said that certain movements are from the first necessarily associated with certain sensations, it is difficult to see why they should not be equally associated with the impressions by which the sensations are produced. Sensation is a *psychical* phenomenon. It is the communication to the mind of a certain organic change in the nervous system. It is the first step in the train of purely mental operations; and these terminate in the formation of an emotional or volitional impulse, which reacts on the body. But we have no reason to believe that sensation can itself react on the body; or that, if it could, it would be a better guide than the impression which produced it. Thus—

Impression a produces
sensation A, with which is associated
motion α;

and in like manner,

impression b produces
sensation B, with which is associated
motion β.

There seems no valid reason, then, to assert that a motion may not have an equally close connection with the *impression*, as it is asserted to have with the *sensation* resulting from it.

181. The question has been often put to those who advocate this view, —why the sensation should be so constantly associated with these changes, if not essential to produce motion? An objection might fairly be made to any reasoning from final causes, in a question of facts; but the inquiry may be easily answered. In many instances the production of sensations is the stimulus necessary for the excitement of other actions, which are required for the continued maintenance of those in question. This may be rendered more comprehensible by a simple illustration. A cistern filled with water may be speedily emptied by a cock occasionally opened at the bottom; but, if it communicate with a reservoir, by means of a valve opened by a ball floating on the surface of the water it contains, it may be kept constantly full. The channel is opened, and the water flows out; and, in consequence of the lowering of the surface thus produced, the floating valve is opened, and the cistern is refilled from the reservoir. Now here the action of the ball-cock at the top is not essential to the flow of water at the bottom, but is rather consecutive upon it. Just so is it with regard to those movements of Animals, which are concerned in the ingestion of their food. The muscular contractions required to propel it along the alimentary canal, from the stomach downwards, are provided for without even the intervention of the nervous system. To bring it within reach of these, a muscular apparatus is provided, by which any thing that comes within its grasp is conveyed downwards, through a reflex operation, originating in the impression made upon the surface of the pharynx. Now this, in the ordinary condition, may be considered as attended with sensation, in order that those other movements may be performed, which will bring food within the reach of the

apparatus of deglutition. The Polype is dependent for its supplies of aliment, upon what the currents in the surrounding fluid, or other chances, bring into its neighbourhood; but any thing which touches its tentacula is entrapped and conveyed into its stomach. The anencephalous infant, again, can swallow, and even suck; but it can execute no other movements adapted to obtain the supply of food continually necessary for maintenance, because it has not a mind which sensations could awake into activity.

182. The sensation connected with reflex actions has not only this important end, but it frequently contributes to enjoyment, as in suction and ejaculatio seminis. Now there is evidence that the latter of these processes, involving though it does the combined action of a number of muscles, and dependent as it seems upon sensation of a very peculiar kind, may take place without consciousness on the part of the individual. Brachet mentions a case of this kind in the Human subject, in which the patient's own testimony could be adduced; and he ascertained that emission could be produced in dogs, in which the spinal cord had been divided in the back, and in which, therefore, it can scarcely be doubted that the sensibility of the genital organs was destroyed. Such cases, it might be thought, are sufficient to prove that the power of the Reflex function, operating independently of sensation, is not confined to such irregular convulsive movements as are seen in Man after disease or injury, but is exercised in producing the regular combined actions, which are necessary for the maintenance of the organic functions. The sensation accompanying these actions, moreover, frequently affords premonition of danger, or gives excitement to supplementary actions destined to remove it, as in the case of respiration; for where any thing interferes with the due discharge of the function, the uneasy sensation that ensues occasions unwonted movements, which are more or less adapted to remove the impediment, in proportion as they are guided by judgment as well as by consciousness. Again, sensation often gives warning against inconvenience, as in the excretory functions; and here it is very evident that its object is not only (if at all) to excite the associated muscles necessary for the excretion, but actually to make the will set up the antagonizing action of the sphincters, as will be hereafter explained. There is one unequivocal case, in the ordinary condition of the human body, of reflex action without sensation; this is the muscular contraction by which the food is propelled from the bottom of the pharynx to the stomach. Unless the morsel be very bulky, so as to press on the surrounding parts, or be very different in temperature from the surface it touches, or have any peculiar irritating quality, we are not more conscious of its presence whilst it is passing down the lower part of the œsophagus, than when it is being propelled along the intestinal tube; and yet, as Dr. J. Reid's experiments* have shown, this contraction is of a reflex character, not being stimulated by direct contact, but requiring the completeness of the nervous circle for its performance.

183. We shall now separately consider the chief operations in which the Spinal Cord and its system of nerves are usually concerned, in the ordinary course of the vital actions of the Human body. Upon taking a general survey of these, it will be found that their ordinary function is, to supply the conditions requisite for the maintenance of the various organic processes. Thus, the aeration of the blood, which takes place whenever that fluid is placed in relation with the atmosphere, can only be carried on by the regular exchange of the small quantity of the gas contained in the lungs; if this

* Edinb. Med. and Surg. Journ.

cease, the circulation is soon brought to a stand, and loss of vitality of the whole system speedily results. Hence this is the most constantly necessary of all the actions of the Spinal Cord; and we find its maintenance, in spite of accident or disease of the spine, remarkably provided for, in the location of the centre of the respiratory movements, which occupies a position where it receives the greatest possible amount of protection. The supply of the digestive apparatus, again, is immediately dependent upon the spinal system; and this, being another essential function, has its centre equally protected. The outlets of the cavities are also controlled by the spinal system; but this function, although essential to the comfort of life, is less necessary to its maintenance; and we find it dependent upon a portion of the cord which is more liable to lose its powers by disease or injury. It is possible, as will hereafter be shown, that several actions, which are at first voluntary, may be effected, when so frequently performed as to become habitual, through the medium of the spinal system: of this kind seem to be the movements of locomotion, which are continued involuntarily, when the whole attention of the mind is given to other objects, but which the will can check at any time. We shall commence our particular survey of the Reflex movements in Man, with the consideration of those of Respiration, which are well adapted for illustrating their general character.

Respiratory Movements.

184. The centre of the Respiratory movements is the upper part of the Medulla Oblongata: into this may be traced the excitor nerves that convey the stimulus on which the movements are dependent; and from it proceed, either directly or indirectly, the motor nerves by which they are carried into effect. The chief Excitor of the respiratory movements is unquestionably the Par Vagum. When this is divided on both sides, according to the experiments of Dr. Reid,* the number of respiratory movements is considerably diminished, usually about one-half. Now if this nerve excites the actions of respiration by its powerful action in producing sensation, we should expect to find its trunk endowed with considerable sensibility, which is not the case; for all experimenters agree in stating that, when its trunk is pinched or pricked, the animal does not exhibit signs of pain nearly so acute, as when the trunks of the ordinary spinal nerves, or of the fifth pair, are subjected to similar treatment. It cannot be questioned, however, that its power as an excitor of respiration is very great, since, besides the fact of the diminution in the number of inspirations which occurs immediately on section of it, irritation of its trunk in the neck is instantly followed by an act of inspiration. It is evident that this power must arise from impressions made upon its peripheral extremities. The impression is probably due to the presence of venous blood in the capillaries of the lungs; or, as Dr. M. Hall thinks, to the presence of carbonic acid in the air-cells. Either or both may be true. The pneumogastric nerve, however, is not the only excitor of the respiratory movements; since, when the nerve is cut on each side, they still continue. Dr. Reid has satisfactorily shown the statement of many experimenters, that the inspirations are *increased* in frequeney after this operation, to be erroneous; this idea having originated in their very prolonged and laborious character. The removal of the encephalon, also, diminishes the frequency of the respiratory movements, whether it be performed before or after the section of the vagi. Dr. Reid found that, in a

* Edinb. Med. and Surg. Journ. Vol. LI.

kitten of a day old, in which the inspirations were 100 per minute, they fell to 40 when the encephalon was removed; and on subsequently cutting the pneumogastrics, the number of inspirations instantly fell to between 3 and 4 in the minute, and continued so for some time. Hence it appears that the respiratory movements are partly dependent upon cerebral agency or volition; and this may also be learned from the prolonged and laborious character of the inspirations during sleep or profound attention, when the influence of the cerebrum is more or less suspended.

185. But why (it may be asked) do the movements continue, when the pneumogastrics have been divided, and the encephalon has been removed? It is evident that there must be other excitors to the action of the respiratory muscles. Amongst these, the nerves distributed to the general surface, and particularly to the face, probably perform an important part; and in exciting the first inspiration, the fifth pair seems the principal agent. It has long been a well known fact, that the first inspiratory effort of the new-born infant is most vigorously performed when the cool external air comes into contact with the face; and that impressions on the general surface, such as a slap of the hand on the nates, are often effectual in exciting the first inspiratory movements, when they would not otherwise commence. Dr. M. Hall relates an interesting case in which the first inspiration was delayed, simply because the face was protected by the bed-clothes from the atmosphere; and, on lifting up these, the infant immediately breathed. Every one knows the fact that the first plunge into cold water, the first descent of the streams of the shower-bath, or even dashing a glass of cold water in the face, will excite inspiratory efforts. That the nerves of the general surface are concerned in this, appears from an experiment of Dr. Reid's. After dividing the pneumogastrics, and removing the brain and cerebellum, he divided the spinal cord high up in the neck, so as to cut off the communication between the spinal nerves and the Medulla Oblongata; and he found that the frequency of the respiratory movements was still further diminished, although they were not even then entirely suspended. It may be surmised, however, that the Sympathetic nerve, which derives many filaments from the cerebro-spinal system, and especially communicates with the pneumogastric nerves, is one of the excitors to this function; and this, perhaps, not only through its ramifications in the lungs, which are considerable, but also by its distribution on the systemic vessels; so that it may convey to the spinal cord the impression of imperfectly arterialized blood circulating in these, such as the pneumogastric is believed to transmit from the lungs. It will hereafter be shown that an impression of a corresponding kind is more probably the cause of the sense of hunger and thirst, than any which originates in the stomach alone. The Motor or Efferent nerves concerned in the function of Respiration are those which Sir C. Bell has grouped together in his respiratory system. The most important of these, the Phrenic, arises from the upper part of the Spinal Cord; the Intercostals much lower down; whilst the Facial nerve and the Spinal Accessory, to the latter of which, as will presently be stated, the motor powers of the par vagum are chiefly due, take their origin in the medulla oblongata itself. But we must not decide upon the connection of a particular nerve with a particular segment of the spinal cord, simply because it diverges from it at that point. It has been shown that, in the Mollusca, a nerve passing to, or proceeding from, one ganglion, frequently passes through or over another which lies in its course; and in the Articulata, this is a still more constant occurrence. It is by no means improbable, then, that the connection of the intercostal nerves is really in part with the grey matter of the medulla oblongata; at

any rate, such a connection has not been disproved. The white columns of the Spinal Cord consist of fibres which bring the spinal nerves into connection, not only with the brain, but also with other segments of the ganglionic portion of the cord; being analogous in function, not only to the distinct fibrous tract of the ventral column of the Articulata, but also to the fibrous bands that connect the ganglia themselves. As the Medulla Oblongata, in Vertebrate animals, is the chief centre of the actions of Respiration, it can scarcely be doubted that all the nerves concerned in that function have a direct structural connection with it.

186. That the Respiratory movements, as ordinarily performed, are essentially independent of the will, appears not only from our own consciousness, but also from cases of paralysis; in some of which the power of the will over the muscles has been lost, whilst the movements have been kept up by the reflex action of the medulla oblongata or respiratory ganglion; whilst in others, some of the respiratory muscles have been motionless during ordinary breathing, and yet have remained under the power of the will. Such cases are mentioned by Sir C. Bell, in the Appendix to his work on the Nervous System. That consciousness is not a necessary link in the chain of causes that produce the respiratory movements, we are enabled to judge from the phenomena presented by the human being in sleep and coma, by anencephalous fœtuses, and by decapitated animals. Further, Dr. Ley* has put on record a case which confirms this particular inference, just in the same manner as the cases already related confirm the general doctrine of the non-existence of sensibility in the Spinal Cord. He had under his care a patient in whom the par vagum appeared to be diseased; the lungs suffered in the usual way in consequence, and the patient had evidently laborious breathing; but he distinctly said that he felt no uneasiness in his chest. The experience of every one informs him, that Respiratory movements are partly under the control and direction of the will, though frequently unrestrainable by it. In ordinary circumstances, when the blood is being perfectly aerated, and there is a sufficient amount of arterial blood in the system to carry on the functions of life for a short time, we can suspend the respiratory actions during a few seconds, without any inconvenience. If, however, we endeavour to prolong the suspension, the stimulus conveyed by the excitor nerves to the medulla oblongata becomes too strong, and we cannot avoid making inspiratory efforts; and if the suspension be still further prolonged, the whole body becomes agitated by movements which are almost of a convulsive nature; and no effort of the will can then prevent the ingress of air.† It is easy to understand why, in the higher animals at least, and more especially in Man, the respiratory actions should thus be placed under the control of the will, since they are subservient to the production of those sounds by which individuals communicate their feelings and desires to each other, and which, when articulate, are capable of so completely expressing what is passing in the mind of the speaker. If the respiratory muscles of Man were no more under his control than they

* On Laryngismus Stridulus, p. 417.

† The Author has heard it stated, though he knows not the authority, that no person ever committed suicide, though many have attempted to do so, by simply holding the breath; the control of the will over the respiratory muscles not being sufficiently great to antagonize the stimulus of the "besoin de respirer," when this has become aggravated by the temporary cessation of the action. But such persons have succeeded better, by holding the face beneath the surface of water; because here another set of muscles is called into action, which are much more under the control of the will than are those of respiration; and a strong volition applied to these can prevent all access of air to the lungs, however violent may be the inspiratory efforts.

appear to be in the Insect or Molluscous animal, he might be provided with the most perfect apparatus of speech, and yet he would not be able to employ it to any advantage.

187. The motor power of the respiratory nerves is exercised, however, not only on the muscles which perform the inspiratory and expiratory movements, but on those which guard the entrance to the wind-pipe, and also on certain other parts. The movements of the internal respiratory apparatus are chiefly, if not entirely, effected through the medium of the motor fibres, which the par vagum contains. These motor fibres exist in very different amount in its different branches. For example, the pharyngeal and œsophageal branches, by which (as will hereafter appear) the muscles of deglutition are excited to contraction, possess a much larger proportion of them, and exhibit much less sensibility when irritated, than do other divisions of the trunk. Between the superior and inferior laryngeal nerves, again, there is an important difference, which anatomical and experimental research have now very clearly demonstrated. The superior laryngeal branch is almost solely an afferent nerve, its motor endowments being limited to the crico-thyroid muscle, to which alone of all the muscles its filaments can be traced, the remainder being distributed beneath the mucous surface of the larynx. The sensibility of this nerve is very evident when it is pinched or irritated during experiments upon it. On the other hand, the inferior laryngeal nerve is almost entirely one of motion, as is shown by its very slight sensibility to injury, its nearly exclusive distribution to muscles, and its influence in exciting contraction of these when its separated trunk is stimulated.

188. It has long been known, that section of the Par Vagum in the neck, above the inferior laryngeals, is frequently followed by suffocation, resulting from closure of the glottis; and hence it has been inferred that the office of the inferior laryngeals was to call into action the dilators of the larynx, whilst the superior laryngeals were supposed to stimulate the constrictors. This view, however, is incorrect. It is inconsistent with the results, just stated, of anatomical examination into the respective distribution of these two trunks; and it has been completely overthrown by the very careful and satisfactory experiments of Dr. J. Reid, which have established that, whilst the inferior laryngeal is the motor nerve of nearly all the laryngeal muscles, the superior laryngeal is the excitor or afferent nerve, conveying to the medulla oblongata the impressions by which muscular movements are excited. It has been ascertained by Dr. R. that, if the inferior laryngeal branches be divided, or the trunk of the par vagum be cut above their origin from it, there is no constriction of the glottis, but a paralyzed state of its muscles. After the first paroxysm occasioned by the operation, a period of quiescence and freedom from dyspnœa often supervenes, the respirations being performed with ease so long as the animal remains at rest; but an unusual respiratory movement, such as takes place at the commencement of a struggle, induces immediate symptoms of suffocation, the current of air carrying inwards the arytenoid cartilages, which are rendered passive by the paralyzed state of their muscles; and these, falling upon the opening of the glottis like valves, obstruct the entrance of air into the lungs. The more effort is made, the greater will be the obstruction; and accordingly, it is generally necessary to counteract the tendency to suffocation, when it is desired to prolong the life of the animal after this operation, by making an opening into the trachea. Dr. Reid further ascertained, that the application of a stimulus to the inferior laryngeal nerves, when separated from the trunk, would occasion distinct muscular contractions in the larynx; whilst a cor-

responding stimulus applied to the superior laryngeal occasioned no muscular movement, except in the crico-thyroid muscle. But when the superior laryngeals were entire, irritation of the mucous surface of the larynx, or of the trunks themselves, produced contraction of the glottis and efforts to cough; effects which were at once prevented by dividing those nerves, and thereby cutting off their communication with the medulla oblongata. There can be no doubt, then, that the superior and inferior laryngeal branches constitute the circle of incident and motor nerves by which the aperture of the glottis is governed, and by which any irritation of the larynx is made to close the passage, so as to prevent the entrance of improper substances; whilst the superior laryngeal nerve also excites the muscles of expiration, so as to cause the violent ejection of a blast of air, by which the offending gas, fluid, or solid, may be carried off. The effect of carbonic acid in causing spasmodic closure of the glottis is well known, and affords a beautiful example of the protective character of this system of nerves.

189. The mucous surface of the trachea and bronchi appears, from the experiments of Valentin, to be endowed with impressibility, so that stimuli applied to it produce expiratory movements; and this evidently operates through the branches of the par vagum distributed upon the membrane. Here, as elsewhere, we find that a stimulus applied to the surface has a much more decided influence than irritation of the trunk of the nerve supplying it. Valentin has succeeded in producing distinct contractions of the rings of the trachea, by irritating the par vagum in the rabbit; and he thinks it probable that a similar action might be induced in the bronchi and their ramifications; but this he has not succeeded in procuring. The phenomena of asthma, however, leave little room for doubt, that spasmodic contraction of the air passages takes place as a reflex action, excited by various causes; and no other nerve but the par vagum can be concerned in producing it.

190. The influence of the Spinal cord, and of its system of nerves, on the movements of Respiration, affords an excellent example of the importance of this organ, as supplying the conditions immediately requisite for the maintenance of the organic functions. We have seen that, strictly speaking, the act of Respiration, as we commonly understand it, is not Respiration itself; for *this* consists in the interchange of ingredients between the blood and the surrounding medium, which is effected in the air-cells of the lungs, and which takes place in the lower animals (as in plants) without any muscular effort. But, in proportion to the necessity for the energetic exercise of this function, do we find a special provision in the higher classes, for the constant renewal of that portion of the surrounding medium which is in contact with the aerating surface; and this comes to be so necessary, that asphyxia might be produced, without any interruption to the ingress of air through the trachea, by merely breaking the circle of nervous action through which the movements of Respiration are effected. It is an interesting circumstance, however, which shows the provision made in the animal frame to meet its necessities, that a very small portion only of the nervous centres is involved in this action; and that, even in the highest Animals, all the rest may be removed, or may be rendered functionally inactive, without checking it. This fact, which was ascertained by Legallois, harmonizes well with that which comparative anatomy has brought under our notice; for it has been shown that, in the lowest group of Mollusca, but a single ganglion exists; and that this is almost exclusively concerned in regulating the entrance and egress of the currents of water, the most constant office of which is the aeration of the blood (§ 133).

Deglutition and Defecation.

191. Another very important function of the Spinal Cord (and of the ganglia corresponding to it in the Invertebrata), is the control which it exercises over the entrance and termination of the Alimentary Canal; and this reflex action might probably be traced in some animals, in which the necessity for that already described does not exist. In all beings which are unequivocally of an animal character, a stomach or digestive cavity exists; and a means must be provided for the introduction of food into it. This is partly provided for by the power with which its entrance is endowed, of contracting, and of attempting to draw inwards whatever comes in contact with it, as we may readily observe in the Star-Fish, or Sea-Anemone, where the mouth is simply the aperture of the stomach. From the analogy of the higher animals, as well as from what has been observed in the lower, it seems probable that *this* action is of a reflex character, depending upon an impression conveyed to the nervous centres, and reflected back to the muscular fibres. But we almost always find some more special apparatus than this, for bringing food within reach of the orifice of the stomach. In the Sea-Anemone, the Hydra, and other Polypes, for example, we find that aperture surrounded by tentacula, which have an evident tendency to lay hold of any thing that touches them, so as to bring it, by their contraction, within reach of the muscles immediately surrounding the orifice. This is just the purpose of the pharyngeal muscles of Man. The lower part of the œsophagus, near its termination in the stomach, has the same simple tendency to contraction from above downwards (so as to convey into the stomach any thing which is brought within its reach) as have the muscles surrounding the mouth of the Polype; but there is need of some more complex apparatus, for the purpose of laying hold of the food, and of conducting it into its grasp. This is provided for, in the higher animals, in the muscles of that funnel-like entrance to the œsophagus, which is called the pharynx. The actions of these are most distinctly reflex; and it is interesting to remark, that the movements can neither be caused nor controlled by the direct influence of the will. In the case of the movements of respiration, we found a sufficient provision made for their constant maintenance; and yet, for secondary purposes, they were placed in a considerable degree under the control of the brain. But here there are no secondary purposes to be answered; the introduction into the stomach of food brought by the will within reach of the pharyngeal muscles, is the only object contemplated by them; and they are accordingly placed under the sole government of the Spinal Cord. No attempts, on our own part, will succeed in producing a really voluntary act of deglutition. In order to excite it, we must supply some stimulus to the fauces. A very small particle of solid matter, or a little fluid, (saliva, for instance,) or the contact of the back of the tongue itself, will be sufficient; but without either of these, we cannot swallow at will. Nor can we restrain the tendency, when it is thus excited by a stimulus; every one knows how irresistible it is, when the fauces are touched in any unusual manner; and it is equally beyond the direct control of the will, in the ordinary process of eating,—voluntary as we commonly regard this. The only mode in which the will can influence it, is by regulating the approach of the stimulus necessary to excite it; thus, we voluntarily bring a morsel of food, or a little fluid, into contact with the surface of the fauces, and an act of deglutition is then involuntarily excited; or we may voluntarily keep all stimulus at a distance, and no effort of the will can

then induce the action. Moreover, this action is performed, like that of respiration, when the power of the will is suspended, as in profound sleep, or in apoplexy affecting only the brain; and it does not seem to be at all affected by the entire removal of the brain in an animal that can sustain the shock of the operation; being readily excitable, on stimulating the fauces, so long as the nervous structure retains its functions. This has been experimentally proved by Dr. M. Hall; and it harmonizes with the natural experiment sometimes brought under our notice in the case of an anencephalous infant, in which the power of swallowing seems as vigorous as in the perfect one. But, if the nervous circle be destroyed, either by division of the trunks, or by injury of any kind to the portion of the nervous centres connected with them, the action can no longer be performed; and thus we see that, when the effects of apoplexy are extending themselves from the brain to the spinal cord, whilst the respiration becomes stertorous, the power of Deglutition is lost, and then respiration also speedily ceases.

192. Our knowledge of the nerves specially concerned in this action is principally due to the very careful and well-conducted experiments of Dr. J. Reid.* The distribution of the Glosso-Pharyngeal evidently points it out as in some way connected with it; and Sir C. Bell, misled by imperfect knowledge of its anatomy, pronounced it to be a *muscular* nerve, whose function was to perform the combined movements of the tongue and pharynx, which are required for deglutition, and also in some acts of respiration. He was not aware that such a combination of movements may be due as much to the *excitor* nerve, and to its termination in the Spinal Cord, as to the *motor*, and its particular distribution to muscles. The function of the Glosso-Pharyngeal nerve has been for some time one of the *quæstiones vexatæ* of physiology; and the results obtained by different experimenters are so strangely at variance, as almost to lead to the belief that they have operated on different nerves. In this dilemma, we may advantageously have recourse to anatomical examination of its distribution; and this, when carefully conducted, discloses the important fact, that the nerve scarcely sends any of its branches to the muscles which they enter; but that these mostly pass through them, to be distributed to the superjacent mucous surface of the tongue and fauces. Further, when the trunk is separated from the nervous centres, irritation scarcely ever produces muscular movements. Hence it is not an efferent or motor nerve, in any great degree; and its distribution would lead us to suppose its function to be, the conveyance of impressions from the surface of the fauces to the medulla oblongata. This inference is fully confirmed by the fact that, so long as its trunk is in connection with the medulla oblongata, and the other parts are uninjured, pinching, or other severe irritation of the glosso-pharyngeal, will excite distinct acts of deglutition. Such irritation, however, may excite only convulsive twitches, instead of the regular movements of swallowing; and it is evident that, here as elsewhere, the impressions made upon the extremities of the nerves are much more powerful excitors of reflex movement, than those made upon the trunk, though the latter are more productive of pain. It was further observed by Dr. Reid, that this effect was produced by pinching the pharyngeal branches only; no irritation of the lingual division being effectual to the purpose.

193. If, then, the muscles of deglutition are not immediately stimulated to contraction by the glosso-pharyngeal nerve, it remains to be inquired, by what nerve the motor influence is conveyed to them from the medulla

* Edinb. Med. and Surg. Journ. Vol. XLIX.

oblongata; and Dr. Reid has been equally successful in proving, that this function is performed by the pharyngeal branches of the Par Vagum. Anatomical examination of their distribution shows, that they lose themselves in the muscles of the pharynx; and whilst no decided indications of suffering can be produced by irritating them, evident contractions are occasioned when the trunk, separated from the brain, is pinched or otherwise stimulated. It appears, however, that neither is the Glosso-Pharyngeal the sole excitor nerve, nor are the pharyngeal branches of the Par Vagum the sole motor nerves, concerned in deglutition; for after the former has been perfectly divided on each side, the usual movements can still be excited, though with less energy; and, after the latter have been cut, the animal retains the means of forcing small morsels through the pharynx, by the action of the muscles of the tongue and neck. From a careful examination of the actions of deglutition, and of the influence of various nerves upon them, Dr. Reid draws the following conclusions:—The impressions are conveyed to the medulla oblongata chiefly through the Glosso-Pharyngeal, but also along the branches of the Fifth pair distributed upon the fauces, and probably along the branches of the Superior Laryngeal distributed upon the pharynx. The motor influence passes chiefly along the pharyngeal branches of the Vagus; along the branches of the Hypoglossal, distributed to the muscles of the tongue, and to the sterno-hyoid, sterno-thyroid, and thyro-hyoid muscles; along the motor filaments of the Recurrents, ramifying upon the larynx; along some of the branches of the Fifth, supplying the elevator muscles of the lower jaw; along the branches of the Portio Dura ramifying upon the digastric and stylo-hyoid muscles, and upon the muscles of the lower part of the face; and probably along some of the branches of the Cervical plexus, which unite themselves to the descendens noni.

194. When the food has been propelled downwards by the pharyngeal muscles as far as their action extends, its further progress through the œsophagus is effected by the peristaltic movement of the muscular coat of the tube itself. This movement is not, however, due to the *direct* stimulus of the muscular fibre by the pressure of the food, as it seems to be in the lower part of the alimentary canal; for Dr. J. Reid has found, by repeated experiment, that the continuity of the œsophageal branches of the Par Vagum with the Spinal Cord, is necessary for the propulsion of the food; so that it can scarcely be doubted, that an impression made upon the mucous surface of the œsophagus, conveyed by the afferent fibres of these nerves to the Medulla Oblongata, and reflected downwards along the motor fibres, is the real cause of the muscular contraction. If the Par Vagum be divided in the rabbit, on each side, above the œsophageal plexus, but below the pharyngeal branches, and the animal be then fed, it is found that the food is delayed in the œsophagus, which becomes greatly distended, and that no more passes into the stomach than is absolutely forced down by the contractions of the pharynx above. Further, if the lower extremity of the par vagum be irritated, distinct contractions are seen in the œsophageal tube, proceeding from above downwards, and extending over the cardiac extremity of the stomach. We have here, then, a distinct case of *reflex action without sensation*, occurring as one of the *regular associated movements* in the natural condition of the animal body; and it is very interesting to find this following upon a reflex action *with* sensation (that of the pharynx), and preceding an action which is altogether unconnected with the Spinal Cord (that of the lower part of the alimentary canal). The use of sensation in the former case will presently appear. It is by no means impossible, however, that the muscular fibres of the œsophagus may be *also*

excitable, though usually in a less degree, by *direct* stimulation; for it appears that, in some animals (the Dog, for example), section of the pneumogastric does not produce that check to the propulsion of the food, which it occasions in the Rabbit.* Moreover, there are many cases in which no such excitability manifests itself in the ordinary condition of the system, but in which it becomes evident when the muscular structure has gained an increase of irritability by diseased action, as we frequently have to notice in the intestinal canal. For example;—in many cases of disease or injury of the Spinal Cord, the bladder ceases to expel its contents, through the interruption of the circle of reflex actions hereafter to be described; but, after a time, it ceases to become necessary to draw off the urine by the catheter; for the fluid is constantly expelled, as soon as it has accumulated in small quantities. In such cases, the mucous coat is found after death to be thickened and inflamed; and the muscular coat is greatly increased in strength, and contracted upon itself. Here, then, the muscular coat, which is not excited to contraction as long as the mucous coat is in a healthy condition, acquires a degree of abnormal irritability, which is sufficient to enable it of itself to expel the urine; but this could not be the case, unless it had originally been possessed of independent contractility. Hence, therefore, the ordinary provision for the peristaltic movements of the œsophagus, through the nervous system, does not disprove the view, which other circumstances render probable, that they may be also performed through the *direct* contractility of the muscular fibres of the œsophagus.

195. It will be desirable here to revert for a short time to the actions which, in the higher animals, precede those of Deglutition. There can be no doubt that, in the Human being, the motions adapted to the ingestion and mastication of aliment originally result, in part at least, from distinct operations of the will; but it would appear almost equally certain that, in time, they come to be of so habitual a character, that the will only exerts a general controlling influence over them, each individual act being excited through the shorter channel already alluded to (§ 183). Every one is conscious that the act of mastication may be performed as well, when the mind is attentively dwelling on some other object, as when it is directed to *it;* but, in the former case, one is rather apt to go on chewing and rechewing what is already fit to be swallowed, simply because the will does not exert itself to check the action, and to carry the food backwards within the scope of the muscles of deglutition. We now see why sensation should be associated with the latter process. The conveyance of food backwards to the fauces is a distinctly voluntary act; and it is necessary that it should be guided by the sensation there produced by the contact which it induces. If the surface of the pharynx were as destitute of sensation as is the lower part of the œsophagus, we should not know when we had done what was necessary to excite its muscles to operation. The muscles concerned in the Mastication of food are nearly all supplied by the third branch of the Fifth pair, a large proportion of which is well known to have a motor character. Many of these muscles, especially those of the cheeks, are also supplied by the portio dura of the Seventh; and yet, if the former be paralyzed, this cannot stimulate them to the necessary combined actions. Hence we see that the movements are of an associated character, their due performance being dependent on the part of the nervous centres from which the motor influence origi-

* It is possible that this may be due to the fact, that the par vagum anastomoses with the sympathetic at the upper part of the neck, more freely in the Dog, than in the Rabbit and many other animals; so that the influence of the œsophageal nerves may be propagated through the sympathetic, when the trunk of the par vagum is divided.

nates. If the Fifth pair, on the other hand, be uninjured, whilst the Seventh is paralyzed, the movements of Mastication are performed without difficulty; whilst those connected in any way with the Respiratory function, or with Expression, are paralyzed.

196. Comparative anatomy supplies us with the key to the explanation of these phenomena. It has been seen that, in the lower animals, the Respiratory organs are completely unconnected with the mouth, and that a very distinct set of muscles is provided to keep them in action. These muscles have distinct ganglia as the centres of their operations; and these ganglia are only connected indirectly with those of the sensori-volitional system. The same would appear to be the case, in regard to the introduction of the food into the digestive apparatus. It has been shown that the muscles concerned in this operation have their own centres,—the stomato-gastric and pharyngeal ganglia,—which are not very closely connected with the cephalic, or with the respiratory, or with those of general locomotion. Now in the Vertebrata, the distinct organs have been so far blended together, that the same muscles serve the purposes of both; but the different sets of movements of these muscles are excited by different nerves; and the effect of division of either nerve is to throw the muscle out of connection with the function to which that nerve previously rendered it subservient, as much as if the muscle were separated from the nervous system altogether. There is an apparent exception to this view of the matter, in the case of the portio dura; this being the source of those movements of the upper lip, which, in many animals, are essential to the prehension of food. These movements, however, are dependent upon *sensations* conveyed through the fifth pair,* being completely checked by division of its infra-orbital trunk; and it can scarcely be doubted, from their general character, that they are of a strictly *voluntary* nature, and are not to be regarded as part of the reflex associated movements in which that nerve is concerned.

197. Now although, in the adult Human being, the movements required to convey the food to the pharynx are under the control of the will, if not constantly dependent upon it, there is good reason to believe that this is not the case in regard to those remarkable associated movements, which constitute the act of suction in the Infant. The experiments provided for us by Nature, in the production of anencephalous monstrosities, fully prove that the nervous connection of the lips and Respiratory organs with the Spinal Cord is alone sufficient for its execution; and Mr. Grainger has sufficiently established the same, by experiment upon puppies whose brain had been removed. He adds that, as one of the puppies lay on its side, sucking the finger which was presented to it, it pushed out its feet in the same manner as young pigs exerts theirs against the sow's dugs. On the whole, however, the act of suction belongs more to the Respiratory ganglion (so to speak) than to the Stomato-gastric system of nerves, and hence we can understand why, even in the highest animals, it should be purely instinctive, the movements of respiration being so from the first, whilst those ordinarily concerned at a later period in the ingestion of the food are more directed by the will. The actions of the mammary fœtus of the kangaroo, described by Mr. Morgan, furnish a very interesting exemplification of the same function of the spinal cord; this creature, resembling an earth-worm

* Hence originated one of Sir C. Bell's early errors. He found that an ass, in which the infra-orbital branch of the fifth was divided, would not pick up oats with its lip, although they were in contact with it; hence he concluded that its power of motion was destroyed, when it was in reality only the sensation necessary to excite the will to cause the motion, that was deficient.

in appearance, and only about fourteen lines in length, with a brain corresponding in degree of development to that of a human fœtus of the ninth week, executes regular, but slow, movements of respiration, adheres firmly to the point of the nipple, and moves its limbs when disturbed. The milk is forced into the œsophagus by a compressor muscle, with which the mamma of the parent is provided. "Can it be imagined," very justly asks Mr. Grainger, "that in this case there are sensation and volition, in what can be proved anatomically to be a fœtus?"

198. We now return to the question of the influence of the Spinal Cord upon the lower part of the alimentary canal. It has been already stated, that the motor function of the Par Vagum appears to terminate at different points in different animals; and this may in part explain the great variety in the results obtained by different experimenters, in regard to the effect of section of the par vagum upon the function of digestion. Valentin agrees with Dr. Reid in stating, that distinct movements of the stomach may be excited in the rabbit by irritation of the par vagum; and he adds, as a precaution, that the experiment should be performed very soon after death, as the irritability of the stomach is soon lost; and that the stimulation of the nerve should not be performed too high up, but rather in the lower part of the neck, or in the thorax. Various experiments upon living animals have led to the belief, that the motions of the muscular parietes of the stomach, which perform a very important part in chymification, are due to the influence of this nerve; food taken in shortly before or subsequently to its division, having been found to be only dissolved on the surface of the mass, where it was in contact with the mucous membrane. But these experiments have been made for the most part upon herbivorous animals, such as horses, asses, and rabbits, whose food is bulky and difficult of solution, requiring to be constantly changed in its position, so that every part of it may be successively brought to the exterior. On the other hand, Dr. Reid found, in his experiments upon dogs, that, after the first shock of the operation had gone off, solution of the food in the stomach, and absorption of chyle, might take place; and hence that no influence of this nerve upon the muscular parietes of the stomach is essential to digestion in that species. This conclusion harmonizes well, therefore, with the fact already stated respecting the absence of such influence in the lower part of its œsophagus; and it may, perhaps, be explained by the consideration, that the natural food of the dog is much less bulky and more easy of solution than that of the animals already named; so that there is not so much need of the peculiar movement, which is in them so important an aid to the process of reduction.

199. In regard to the functions of the afferent portion of the gastric branches of the Par Vagum, there has also been considerable difference of opinion; some physiologists maintaining that it is by impressions on them alone that the sense of Hunger or satiety is occasioned; whilst others deny that it has any power of transmitting such impressions, and maintain that they do not originate in the stomach at all. Dr. Reid has arrived at the conclusion, from his numerous experiments, that the par vagum is the channel through which the mind becomes cognizant of the condition of the stomach; but that it is not the sole excitor of the sense of hunger. Animals which have sustained section of the nerve on both sides, will eagerly take food, if they have not received too great a shock from the operation; but they seem to experience no feeling of satiety when the stomach is loaded. This inference is confirmed by Valentin, who mentions that puppies after the operation will take three times, and even more, the same quantity of milk as uninjured individuals of the same age; so that the abdomen is

greatly distended. The other sources of the sense of hunger will be hereafter considered. The act of Vomiting has been now sufficiently shown to be excitable through the par vagum; an impression propagated through which to the Medulla Oblongata, excites to contraction a considerable number of muscles. But, as in the case of hunger, although the sense of nausea and the tendency to vomit may be excited by various irritating causes operating through this nerve only, it may be produced also through other channels. Thus severe vomiting has been excited by the injection of a solution of tartar emetic or of emetin into the blood-vessels—a fact of which it has been proposed to take advantage in extreme cases of narcotic poisoning, when the nervous system has become so torpid, that emetics administered in the ordinary manner are of no avail. (See § 300.)

200. That the ordinary peristaltic movements of the intestinal canal, from the stomach to the rectum, may take place without any connection with the nervous system, being due to the direct stimulation of the contact of food, there is now ample evidence; and though some may still be found who deny the Hallerian doctrine, that muscular fibre possesses in itself the property of contractility, so much additional evidence of its truth has been recently adduced, whilst the fact itself is so conformable to the analogy supplied by others, that it will be here unhesitatingly adopted. (See Chapter V.) Mr. Grainger and some other physiologists have supposed, that the peristaltic movements of the alimentary canal are due to a sort of reflex action, taking place through the ganglia of the sympathetic system of nerves, especially, of course, the semilunar. This supposition, however, has little or no evidence to support it; for it has been fully proved that the muscular contractions will continue long after the tube has been separated from its nervous connections through its whole extent; and the only evidence in its favour is derived from the contractions which may sometimes be induced in parts of the tube which are at rest, when the sympathetic nerves supplying them are irritated. Some very interesting experiments have been recently published by Valentin, by which the fact that such contractions may be induced (which has been denied by some) is clearly substantiated; but it is also shown that the motor influence does not originate in the Sympathetic ganglia, but in the Spinal Cord. The following are the general results of upwards of three hundred experiments, so far as they apply to this subject. —The pharynx may not only be excited to contraction by irritation of the pharyngeal branches of the Par Vagum, or of the roots of the Spinal Accessory, from which their motor power is derived (as will be hereafter explained), but also by stimulating the roots of the first two Cervical nerves; and the lower part of the œsophagus in the neck is made to contract peristaltically from above downwards, by irritation of the roots of the first three Cervical nerves, and of the cervical portion of the Sympathetic, through which last the former evidently operate. The thoracic portion of the œsophagus is made to contract by irritation of the lowest Sympathetic ganglion of the neck, and of the higher thoracic ganglia, and also of the roots of the lower Cervical spinal nerves. Muscular contractions of the stomach are produced by irritation of the roots of the 4th, 5th, 6th, and 7th Cervical nerves, and of the first thoracic, in the rabbit; so that a distinct furrow is evident between the cardiac and pyloric portion of the viscus; and the lower the nerve irritated, the nearer the pylorus do the contractions extend. Irritation of the first thoracic ganglion of the Sympathetic produces the same effect. Contractions of the intestinal tube, varying in place according to the part of the Spinal Cord experimented on, may be excited by irritation of the roots of the dorsal, lumbar, and sacral nerves, and of the trigeminus;

and similar effects are produced by irritation of the lower part of the thoracic portion of the lumbar, and of the sacral portions of the Sympathetic,—also of the splanchnic, and of the gastric plexus.

201. From these facts it is evident, that the movements of the Intestinal tube may be influenced by the Spinal Cord; and that what is commonly termed the Sympathetic nerve is the channel of that influence, by the fibres which it derives from the spinal system. But it by no means thence follows, that the ordinary peristaltic actions of the muscles in question are dependent on a stimulus reflected through the spinal cord, rather than on one directly applied to themselves. It is clear that, although these movements are of the first importance to the welfare of the system, the means of sustaining them are feeble, compared to those which we find provided for the maintenance of the distinctly reflex actions of deglutition, respiration, &c. The difficulty with which any evidence can be obtained of the connection is a sufficient proof of this. On the other hand, we do know that these peristaltic movements are *influenced* by particular states of mind, or by conditions of the bodily system; and the connection just traced satisfactorily accounts for this, and is itself sufficiently explained. The intestinal tube, then, from the stomach to the rectum, is *not dependent* upon the Spinal Cord for its contractility, but is enabled to propel its contents by its own inherent powers; still we find that here, as in other instances, the nervous centres exert a general control over even the organic functions, doubtless for the purpose of harmonizing them with each other, and with the conditions of the organs of animal life.

202. On examining the outlets by which the excretions are voided, we find that they are placed, like the entrances, under the guardianship of the Spinal Cord; subject, however, to some control on the part of the will. In the lowest animals, the act of discharging excrementitious matter is probably as involuntary, as are those immediately concerned in the introduction of nutriment, and is performed as often as there is any thing to be got rid of. In the higher classes, however, such discharges are much less frequent; and reservoirs are provided, in which the excrementitious matter may accumulate in the intervals. The associated movements required to empty these are completely involuntary in their character; and are excited by the quantity, or stimulating quality, of the contents of the reservoir. But, had volition no control over them, great inconveniences would ensue, hence sensation is excited by the same stimulus which produces the movements; in order that, by arousing the will, the otherwise involuntary motions may be restrained and directed. There can be little doubt, from the experiments of Dr. M. Hall, as well as from other considerations, that the associated movements, by which the contents of the rectum and bladder are discharged, correspond much with those of Respiration,—being in their own nature involuntary, but capable of a certain degree of voluntary restraint and assistance: whilst the discharge of the contents of the vesiculæ seminales would seem to be completely automatic; thus corresponding with the act of deglutition. On the other hand, the sphincters, which antagonize their expellent action, are usually maintained in a state of moderate contraction, so as to afford a constant check to the egress of the contents of the cavities; and this condition has been fully proved by Dr. M. Hall, to result from their connection with the Spinal Cord, ceasing completely when this is interrupted. On the other hand, the sphincter is certainly in part controlled by the will, and is made to act in obedience to the warning given by sensation; and this voluntary power is frequently destroyed by injuries of the Brain, whilst the Spinal Cord remains able to perform all its own functions, so that discharge

of the urine and fæces occurs. In their moderate action, the expulsors and the sphincters may be regarded as balancing one another, so far as their reflex action is concerned,—the latter having rather the predominance, so as to restrain the operation of the former. But, when the quantity or quality of the contents of the cavity gives an excessive stimulus to the former, their action predominates, unless the will is put in force to strengthen the resistance of the sphincter; this we are frequently experiencing, sometimes to our great discomfort. On the other hand, if the stimulus is deficient, the will must aid the expulsors, in order to overcome that resistance which is due to the reflex contraction of the sphincters; of this also we may convince ourselves, when a sense of propriety, or a prospective regard to convenience, occasions us to evacuate the contents of the rectum or bladder without a natural call to do so. The muscular coat of the Bladder is commonly regarded as having, like that of the intestinal tube, no connection with the Spinal Cord; but the experiments of Valentin have shown that a connection exists, as in the former case, through the sympathetic nerve, affecting not only the bladder but also the ureters. That physiologist states that a very distinct and powerful peristaltic action of the ureter, proceeding from the kidneys to the bladder, may be produced by irritating the abdominal ganglia of the Sympathetic, or the roots of the superior abdominal Spinal nerves; and that strong contractions of the bladder are excited by irritation of the inferior portion of the abdominal Sympathetic, but especially of its sacral portion, and of the roots of the middle and inferior abdominal nerves of the Spine. In these, as in former cases, no effect is produced by irritation of the Spinal Nerves, unless the portion of Sympathetic connected with the particular organ be entire.

203. The influence of the Spinal Cord on the Genital organs is of a similar character. The muscular contractions involved in the Emissio Seminis are clearly of a *reflex* character, being independent of the will, and not capable of restraint by it when once fully excited, and being producible in no other way than (like those concerned in Deglutition) by a particular local irritation. That this irritation need *not* amount to a *sensation*, is proved by cases already referred to (§ 182); and it has been also shown by experiment, that section of the Spinal Cord in the lumbar region does not prevent the act from being performed, the lower division only being concerned in the reflexion of the impression. It appears also, from the experiments of Valentin, that the Spinal Cord may operate on the Genital organs through the Sympathetic system. Contractions were excited in the vas deferens and vesiculæ seminales, especially of the Guinea Pig at the time of heat, by irritation of the inferior lumbar and highest sacral portions of the Sympathetic; and the Fallopian tubes, as well as the Uterus itself, may be excited to contraction, by irritation of the same nerves as those which excite the rectum,—namely, the lower lumbar and first sacral nerves of the Spine. This last fact is important in regard to the rationale of the operation of certain medicines, such as aloes, which are known to have an influence on both parts. In regard to the act of Parturition, there would seem reason to believe, from the evidence of cases of paraplegia, that, of the muscles whose operation is associated in it, the diaphragm, abdominal muscles, &c., are called into action (as in defecation) through the Spinal Cord; but that the contractions of the uterus itself are independent of all connection with the nervous centres. Of the reason why the muscles, which were up to that time inert, should then combine in this extraordinary manner, and with such remarkable energy, Physiology can afford no certain information. There can be little doubt, however, that the stimulus usually originates in the

uterus, or in some of the neighbouring organs which are incommoded by the pressure; but it may also result from some condition of the general system, in which the uterus itself is but little concerned. It is an interesting fact, which has been more than once observed, that the fœtus may be expelled from the dying body of the mother, even after the respiratory movements have ceased. This would appear due to the contraction of the uterine fibres alone, which, like those of the heart and alimentary canal, retain their irritability longer than those of the muscles supplied by the cerebro-spinal nerves; and the power of these would be unopposed by the resistance which they ordinarily have to encounter; since the tone of all the muscles surrounding the outlet would be destroyed, by the cessation of the activity of the Spinal system of nerves.

Protecting Agency of the Spinal Cord.

204. From the foregoing details it appears, that one of the chief functions of the Spinal Cord is to control the orifices of the various open cavities of the body; and this function evidently has safety as well as convenience in view. It has been manifestly designed by the All-wise Creator, that the glottis should close against agents injurious to the organs within; and that the effort to vomit should be excited, by the attempt to swallow substances so nauseous as to induce loathing. There is another protective influence exerted by it, of a still more remarkable nature. It has been ascertained by Dr. M. Hall that, if the functions of the Brain be suspended or destroyed, without injury to the Spinal system of nerves, the Orbicularis muscle will contract so as to occasion the closure of the eyelids, upon the tarsal margin being touched with a feather. This fact is interesting in several points of view. In the first place, it is a characteristic example of pure reflex action, occurring under circumstances in which volition cannot be imagined to guide it, and in which there is no valid reason to believe that sensation directs it. Further, it explains the almost irresistible nature of the tendency to winking, which is performed at short intervals by the contraction of the Orbicularis muscle, and which is evidently a Spinal action, capable of being in some degree restrained (like that of respiration) by the will, but only until such time as the stimulus (resulting perhaps from the collection of minute particles of dust upon the eyes, or from the dryness of its surface in consequence of evaporation,) becomes too strong to be any longer resisted. Again, we have in sleep or in apoplexy an example of this purely spinal action, unbalanced by the influence of the will, which in the waking state antagonizes it by calling the levator palpebræ into action. As soon as the will ceases to act, the lids droop, and close over the eye in order to protect it; and if those of a sleeping person be separated by the hand, they will be found presently to return. Here, as in studying the respiratory and other movements, we are led to perceive, that it is the brain alone which is torpid during sleep, and whose functions are affected by this torpidity. As Dr. M. Hall very justly remarks, the spinal system never sleeps; it is constantly in activity; and it is thus that, in all periods and phases of life, the movements which are essential to its continued maintenance are kept up without sensible effort.

205. The closure of the Pupil against a strong light is another movement of the same protective tendency. The channel, through which that just named is performed, is completed by the first branch of the Fifth and the Portio Dura of the seventh. The contraction of the pupil is immediately caused by the Third pair, or Motor Oculi; as is easily shown by irritating

the trunk of that nerve and observing the result. But it is not easy to speak with certainty as to the afferent nerve, by which the motor influence is excited. Although the contraction of the pupil is usually in close accordance with the sensation occasioned by the impression of light upon the retina, yet there is no want of evidence to prove that the sensation of light is not always necessary; for, even when the sight of both eyes has been entirely destroyed by amaurosis, the regular actions have been witnessed in the pupil, in accordance with varying degree of light impinging on the retina. This fact may be explained in two ways. It may either be imagined, that the requisite stimulus is not that of *light* conveyed through the *optic* nerve; but that of *heat* conveyed through the ophthalmic branch of the Fifth pair. Or it may be still supposed, that the motion results from an impression upon the retina, which impression, being conducted to the brain ordinarily produces a sensation; whilst in these curious cases no sensation is produced, on account of a disordered state of the part of the brain in which the Optic nerve terminates; though some filaments of that nerve, being connected with the Spinal Cord, and not with the Brain, can produce a reflex action through the Third pair, although no sensation accompany it. In either view, the rarity of the occurrence is at once accounted for; since in most cases of amaurosis, the disease lies in the trunk of the nerve, and thereby checks both its spinal and its cerebral actions. A protective influence, analogous to that exhibited in the iris, but requiring sensation for its excitement, is also exercised by the Orbicularis, when the eye is exposed to very strong light; and it is remarkably shown, also, in cases of ophthalmia, in which the retina is in an irritable condition. Every oculist is aware with what force the Orbicularis contracts in the strumous ophthalmia of children, in which *photophobia* is generally a leading symptom; and its protecting action is further aided by the muscles of the eye, which roll it beneath the upper lid farther than any voluntary effort could accomplish. The particular muscles and nerves concerned in this action will be hereafter inquired into.

206. The physiologist has not at present any knowledge of any similar protective movements, in the Human being, designed to keep the organ of Hearing from injury; but there can be little doubt that those which we are constantly witnessing in other animals, possessing large external ears, are reflex actions excited by the irritation applied to them. In regard to the Nose, we find a remarkably complex action—that of sneezing—adapted to drive off any cause of irritation. This action, as far as the respiratory movements are concerned, is nearly the same as that of coughing; but the velum palati, at the moment of the expiratory blast, is stretched across the fauces in such a manner, that the whole force of the air is directed through the nostrils, and tends to carry off any irritating solid, fluid, or gas, which may have excited the mucous membrane. It will hereafter be shown that the stimulus is conveyed, in this case, not through the olfactory nerve, but through the fifth pair; so that it is not dependent upon the excitement of the sensation of smell.

Other Functions of the Spinal Cord.

207. The influence of the Nervous Centres in maintaining what is commonly designated as the *tone* of the muscular system, was first distinctly limited by Dr. M. Hall, to the Spinal Cord, and the system of nerves connected with it. By the expression in question is meant, that state of moderate contraction, which causes all the muscles to present a certain degree of

firmness, by their antagonism with each other, when none of them are particularly contracted or relaxed. The following experiments by Dr. M. Hall clearly prove the influence of the Spinal Cord on this functional condition:—"Two Rabbits were taken; from one the head was removed; from the other also the head was removed, and the spinal marrow was cautiously destroyed with a sharp instrument: the limbs of the former retained a certain degree of firmness and elasticity; those of the second were perfectly lax." "The limbs and tail of a decapitated Turtle possessed a certain degree of firmness or tone, recoiled on being drawn from their position, and moved with energy on the application of a stimulus. On withdrawing the spinal marrow gently out of its canal, all these phenomena ceased. The limbs were no longer obedient to stimuli, and became perfectly flaccid, having lost all their resilience. The sphincter lost its circular form and contracted state, becoming lax, flaccid, and shapeless. The tail was flaccid and unmoved on the application of stimuli." It is probable that this tonic contraction is strictly a reflex action; an impression of the condition of the muscle, corresponding with the "muscular sense" of Sir C. Bell, but not necessarily accompanied by sensation, being conveyed to the Spinal Cord, and producing the stimulus to contraction. The want of this tone is seen in the relaxation of the sphincters; and also in the distortion of the face produced by paralysis of the Portio Dura, and resulting from the tonic contraction of the muscles on one side of the face, unbalanced by that of the other side. Cases have occasionally presented themselves, in which the portio dura has been paralyzed to the influence of the will (owing to disease affecting its cerebral termination), whilst its spinal connections have not been affected; so that the tone of the muscles has been preserved, and no distortion of the face has manifested itself, until the muscles were stimulated by a voluntary impulse, to which those of one side only would respond.

208. Nearly allied to this function of the Spinal Cord, is that by which it is subservient to the maintenance of the contractility of muscles paralyzed to the influence of the will. It is well known that, in ordinary cases of paralysis, the muscles lose their irritability in the course of a few weeks, so that no stimulus excites them to contraction; and it is also well known that their characteristic structure is so greatly affected, that, in progress of time, no true muscular fibres can be detected in their place. Experiments on animals, in which portions have been removed from the nerves supplying the limbs, conduct to exactly the same result as the experiments made for us by diseased conditions in Man. Now Dr. M. Hall has pointed out that,—in cases where the muscles are paralyzed to the influence of the will, through disease of the Brain or of the upper part of the Spinal Cord, but retain their power of reflex action, the nervous circle which operates through the Spinal Cord not being interrupted,—the contractility of the muscles is not diminished, but appears to be sometimes even increased; and he has suggested that this fact may be made available as a means of diagnosis in obscure cases of paralysis. Thus, in some cases of Paraplegia, the reflex actions may be excited; in others they cannot be. In the former, the disease must be in the dorsal or cervical portion of the Spinal Cord, leaving its lumbar portion free to carry on the reflex actions, though its connection with the brain is interrupted. In the latter; the disease is probably within the lumbar vertebræ, involving that portion of the Spinal Cord through which the reflex actions of the lower extremities are produced. In like manner, in paralysis of a single arm or of one leg, if the reflex actions, and the contractility of the muscles on the application of a direct stimulus (such as galvanism), remain unimpaired, the cause is probably seated in the Brain;

whilst, if the tone of the muscles is completely lost, and no contraction can be induced in them, the cause of the paralysis is probably somewhere in the neighbourhood of the roots of the nerves of the part affected.—There is no good ground for believing, however, that the contractility of the muscles is directly dependent on their connection with the Spinal Cord,—a doctrine which is inconsistent (as will be shown hereafter) with well established facts. It is well known that muscular structure, like others whose chemical constitution is such as to require constant renewal, requires, for its perfect nutrition, to be kept in a state of functional activity. If the muscles of the leg, for example, be disused for a long time, their nutrition is greatly impaired, and their contractility is almost suspended, even though they retain their connection with the nervous centres, and the latter be in their normal condition. It is to be expected then, that, if a muscle be completely put out of the pale of nervous influence, its nutrition should be speedily impaired, and its contractility altogether lost; but if the influence of the will only be withdrawn from it, and its connection with the Spinal Cord be uninterrupted, it will be in a state of continual action, by the operation of various reflected stimuli; and this action will be sufficient to maintain its nutrition, and to prevent the loss of its contractility. (See Chap. V.)

209. The fact that the action of the Heart is in some degree under the control of the Spinal Cord, has long been known. It is not a little curious that, although its movements will continue regularly after complete section of all its nerves, any sudden and severe impression upon a large part of the Nervous Centres,—such as crushing the Brain or Spinal Cord,—will produce a great diminution in their frequency, or even occasion their entire cessation, if the nervous connection be entire. It will be hereafter shown that the influence is partly communicated by the Par Vagum; but it appears from the experiments of Valentin, that the sympathetic is in part, as in the case of the motions of the alimentary canal, the channel by which it is transmitted. He found that, when the heart had ceased to beat, its contractions might be renewed by irritation of the roots of the Spinal Accessory nerve, and of the first four Cervical nerves, and also of the first cervical ganglion of the Sympathetic. He thinks that he has also witnessed distinct contractions of the thoracic aorta, of the inferior cava, and of the thoracic duct, upon irritation of the neighbouring portion of the sympathetic system, which evidently derives its whole motor power from the spinal cord. The ductus choledochus has also been seen by him to contract on irritation of the right splanchnic nerve.

210. Lastly, we have to inquire how far the Reflex action of the Spinal Cord is concerned in the locomotive actions of the lower extremities in Man. It will be remembered that, in the Dytiscus whose head had been removed (§ 146), the stimulus of the contact of water immediately excited regular and continued locomotive actions, which lasted for some time. So in the cases already quoted (§ 177, 8), when the control of the will over the lower extremities was lost, powerful muscular actions were excited through the Spinal Cord alone. In the healthy condition of the Human system, when the will is controlling all the movements which are not immediately concerned in the maintenance and regulation of the organic functions, no such actions can be excited; but in proportion as its control is lost, does the independent power of the Spinal Cord manifest itself. Hence we can understand that, when the whole attention of the mind is given to other objects, but a certain train of muscular actions has been voluntarily begun, that train will continue under the influence of the constantly renewed stimulus, without any thing more than a *general* sustaining and directing energy on the

part of the will. We all know that, in walking along an accustomed road, we frequently lose even our consciousness of our situation, from the close occupation of the mind upon some train of thought; and yet our limbs continue to move under us with regularity, until we are surprised by finding ourselves at the place of our destination, or peradventure at some other which we had not intended to visit, but to which habit has conducted us. Now in such a case it would be said by some metaphysicians (acknowledging, as all do, that the mind cannot *will* two different things at the same time) that the volition is in a sort of vibratory condition between the two sets of actions—now prompting one, and now the other. But, independently of the manifest complexity which must attend the operations of the mind so employed, it may be shown that it is perfectly conformable to the analogy afforded by psychical phenomena, to refer the habitual series of actions to the shorter train afforded by the Spinal system of nerves, whilst the cerebral system is concerning itself with the other. It is not difficult, then, to understand that the locomotive actions may, by habit, and by the temporary suspension of the particular direction of them by the will, become nearly of the same reflex or excited character as they obviously are in the lower animals. The more such actions are of a simple rhythmical character, similar to those of Respiration, the more does it seem that they may with probability be referred to the Spinal system; and if we attribute to this (as we can scarcely help doing) the rapid vibration of the wings of Insects, there seems no reason why we should not extend the same view to the wings of Birds. Such an explanation of their movements will account for their occasional continuance, without apparent fatigue, during a period through which no known voluntary effort can endure; for it is one of the attributes of the Spinal system of nerves, well pointed out by Dr. M. Hall, that the exercise of the muscles excited by it does not occasion fatigue, the sense of which is cerebral only.

211. It would not be right to conclude this account of the principal functions of the Spinal Cord, without adverting to some of the leading pathological applications of the physiological doctrines, which have been developed in it. A large part of these were first pointed out by Dr. M. Hall; and they are receiving continual and important extensions from his own labours and those of other practical inquirers.* It may be remarked, in the first place, that the power of the whole Spinal system is capable of being morbidly diminished or augmented. It may even be for a time almost completely suspended, as in Syncope, which state may be induced by sudden and violent impressions, either of a mental or physical nature, which operate upon the whole nervous system at once, commencing, however, in the Brain. It is to be remarked, however, that in recovering from these, it is the Spinal system of which the activity is first renewed,—the respiratory movements recommencing, and the power of swallowing being restored, before any voluntary actions can be performed. A corresponding state may be induced in particular portions of the system by concussion, as is seen in severe injuries of the Spinal Cord, which are almost invariably followed for a time by entire suspension of its functions. Again, the power of the whole Spinal

* The student is earnestly requested to make himself well acquainted with the pathological portion of Dr. M. Hall's recently published work on the Nervous System, in which a new field of inquiry is opened, and the extent and importance of the applications of Dr. Hall's physiological doctrines are clearly shown. It is only to be regretted that a volume devoted to scientific investigation should be disfigured by so many personal attacks, many of them completely groundless in their nature, as this contains.

Cord may be diminished by various causes, such as enfeebled circulation, pressure, &c.; and then we have torpidity of the whole muscular system. If oppression exists in the brain, the functions of the Medulla Oblongata will be especially affected; and if it be prolonged and sufficiently severe, Asphyxia will result from the interruption of the respiratory movements which it occasions.

212. On the other hand, the excitability of the whole Cord, or of particular parts of it, may be morbidly increased. This is especially seen in Tetanus, Hydrophobia, and the artificial tetanus induced by Strychnine, so that the slightest external stimulus is sufficient to induce reflex actions in their most terrific forms. It is interesting to remark, that, in these formidable diseases, the functions of the muscles controlling the various orifices are those most affected; and it is by the spasms affecting the organs of respiration or deglutition, that life is commonly terminated. Various remedial agents will probably be found to operate, by occasioning increased excitability in some particular segments of the cord; so that the usual stimuli applied to the parts connected with these, will occasion increased muscular action. This seems to be the case, for example, in regard to the influence of aloes on the rectum and uterus, cantharides on the neck of the bladder and adjoining parts, and secale cornutum on the uterus. The mode of influence of cantharides is illustrated by a curious case, related by Dr. M. Hall, of a young lady who lost the power of retention of urine in consequence of a fatty tumour in the spinal canal, which gradually severed the Spinal Cord, and induced paraplegia. The power of retaining the urine was always restored *for a time* by a dose of tincture of cantharides, which augmented the excitability of the segment of the cord with which the sphincter vesicæ is connected. The researches of Valentin, when grafted (as it were) on the doctrines of Dr. M. Hall, afford the key to the explanation of the numberless sympathetic influences of the organs of nutrition, &c. upon one another, by showing that they are all connected with the Spinal Cord; and that the muscular structure, with which they are all provided, may be excited to contraction through it.

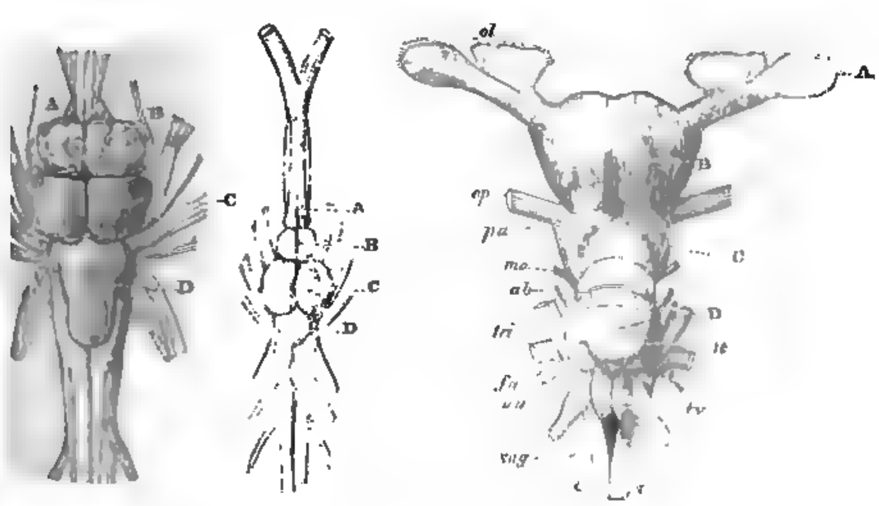
Comparative Anatomy of the Encephalon.

213. The assistance which the Physiologist has hitherto derived from the study of the Comparative Anatomy of the Encephalon in Vertebrata, is not so great as might have been expected; there can be little doubt, however, that much is yet to be learned from it. Certain general inferences appear well established; and it is chiefly in questions of detail, that difficulties still exist. The Encephalon may be described as consisting of the Cerebral Hemispheres, the Cerebellum, and the Medulla Oblongata with its chain of ganglia. The relative proportion of the two former to the latter is such in Man, that its character would not be readily understood by the inspection of *his* Brain alone; and it is one of the most interesting results of the comparison of it with the brains of animals of the inferior tribes, that the great change which we there find in the proportion of the parts, makes evident the importance of what would have been otherwise considered subordinate appendages. This is peculiarly the case in Fishes. There may be noticed in the Encephalon of that class *four* distinct ganglionic enlargements; of which the posterior is usually on the median line, whilst the others are in pairs. The posterior, from its position and connections, is evidently to be regarded in the light of a Cerebellum; and it bears a much larger proportion to the rest in this class than in any other. The pair in front of this are not

the hemispheres of the Cerebrum, as their large size in some instances (the Cod for instance) might lead us to suppose; but they are immediately connected with the Optic nerve, which, in fact, terminates in them, and are therefore to be considered (like the chief part of the cephalic masses of Invertebrated animals) as Optic Ganglia. In front of these are the Cerebral Hemispheres, which are small, generally destitute of convolutions, and possess no ventricle in their interior, except in the Sharks and Rays, in which they are much more highly developed than in the Osseous Fishes. Anterior to these is another pair of ganglionic enlargements, from which the Olfactory nerves arise; and these are, therefore, correctly designated as the Olfactive tubercles or ganglia. In some instances, these ganglia are not immediately seated upon the prolonged spinal cord, but are connected with it by long peduncles; this is the case in the Sharks: and we are thus led to perceive the real nature of the portion of the trunk of the Olfactory nerve in Man, which lies within the cranium, and of its bulbous expansion on the

Fig. 17.

Pike. Cod. Fox-Shark.



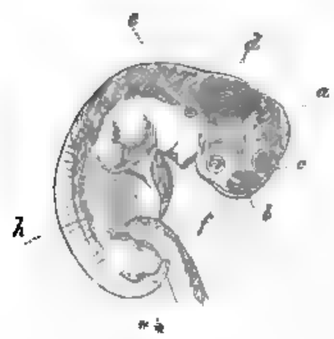
Brains of Fishes, after Leuret, A, olfactive lobes or ganglia, B, cerebral hemispheres; C, optic lobes; D, cerebellum: *ol*, olfactory nerve; *op*, optic nerve; *pa*, patheticus; *mo*, motor oculi; *ab*, abducens; *tri*, trifacial. *fa*, facial; *au*, auditory; *vag*, vagus; *tt*, tubercles or ganglia of the trifacial, *tv*, tubercles of the vagus.

Ethmoid bone. Besides these principal ganglionic enlargements, there are often smaller ones, with which other nerves are connected. Thus, in the Shark, we find a pair of tubercles of considerable size at the origin of the Trifacial nerves; and another pair, in most Fishes, at the roots of the Vagi. In some instances, too, distinct Auditory ganglia present themselves.

214. The Optic Lobes of Fishes have no analogy whatever with the Thalami optici of Mammalia, the connection of which with the Optic nerves is apparent only. They are rather to be compared with the Tubercula Quadrigemina, which are the real ganglia of the Optic nerve. Their analogy is not so complete, however, to these bodies in the fully-formed Brain of Man, as it is to certain parts which occupy their place at an earlier period.

The *Third Ventricle*, which is quite distinct from the Corpora Quadrigemina, is hollowed out, as it were, from the floor of the Optic Lobes of Fishes; and the Anterior Commissure bounds its front: hence these must be considered as analogous to the parts surrounding the Third Ventricle, as well as to the Corpora Quadrigemina. This is made evident by the fact, observed by Müller, that, in the Lamprey, there is a distinct Lobe of the third ventricle, replacing the Optic Lobes of other fishes, and partly giving origin to the optic nerves; and a separate vesicle, analogous to the Corpora Quadrigemina. With this condition, the early state of the Brain in the embryo of the Bird and Mammiferous animal, and even in Man himself, bears a very close correspondence. The Encephalon consists at this time of a series of vesicles, arranged in a line with each other, of which those that represent the Cerebrum are the smallest, whilst that which represents the Cerebellum is the largest. The latter, as in Fishes, is single, covering the fourth ventricle on the dorsal surface of the Medulla Oblongata. Anterior to this, is the single vesicle of the Corpora Quadrigemina, from which the Optic nerve chiefly arises; this has in in its interior a cavity, the ventricle of Sylvius, which exists even in the adult Bird, where the Corpora Quadrigemina are pushed, as it were, from each other by the increased development of the Cerebral hemispheres. In front of this is the vesicle of the Third Ventricle, which contains also the Thalami; as development proceeds, this, like the preceding, is covered by the enlarged hemispheres; whilst its roof becomes cleft anteriorly on the median line, so as to form the anterior entrance to the cavity. Still more anteriorly is the double vesicle, which represents the hemispheres of the Cerebrum; this has a cavity on each side, the floor of which is formed by the corpora striata. The cavity of the cerebral vesicles has at first no opening, except into that of the third ventricle; at a later period is formed that fissure on the inferior and posterior side, which (under the name of the fissure of Sylvius) enables the membranes enveloping the brain to be reflected into the lateral ventricles. Thus it will be seen that the real analogy, between the brain of the Human fœtus and that of the adult Fish, is not so close as, from the resemblance in their external form, might have been supposed.

Fig. 18.



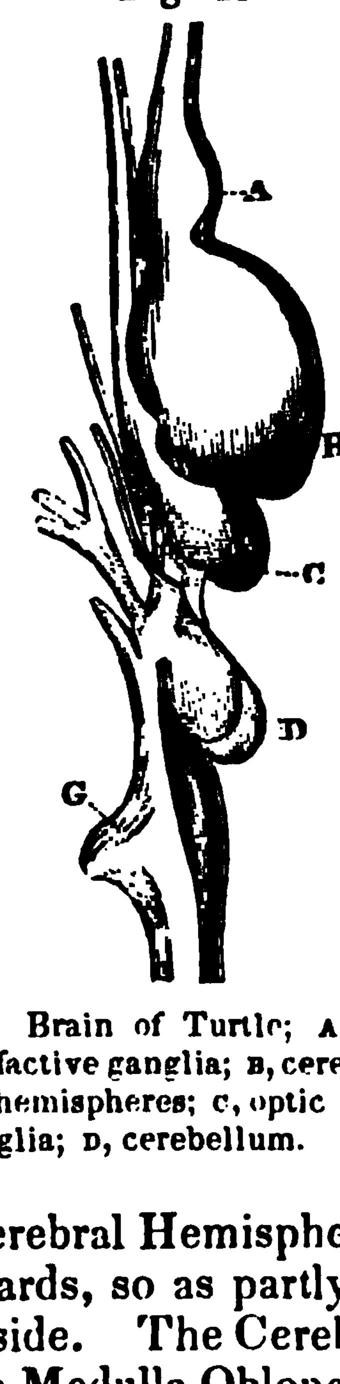
Human embryo of sixth week, enlarged about three times; *a*, vesicle of corpora quadrigemina, *b*, vesicle of cerebral hemispheres; *c*, vesicle of thalami optici and third ventricle; *d*, vesicle for cerebellum and medulla oblongata; *e*, auditory vesicle; *f*, olfactory fossa; *h*, liver; * * caudal extremity. (After Wagner.)

215. In the small proportion which the cerebral hemispheres bear to the other parts, there is evidently a very close correspondence; and this extends also to the general simplicity of their structure, the absence of convolutions, and the deficiency of commissures. But there is a much nearer analogy between the *fœtal* brain of the Fish, and the *fœtal* brain of the Mammal; indeed, at the earliest period of their formation, they could not be distinguished; during their advance to the permanent condition, however, each undergoes changes, which are so much more decided in the higher animals than in the lower, that in the latter there seems but little departure from the fœtal condition, whilst in the former the condition appears entirely changed. Hence it is not correct to assert, as is frequently done,—that the Brain, or

any other organ, in the higher animals, passes through a series of forms which is parallel to the permanent forms of the same organ in different parts of the animal scale; since the fact is rather, that the more nearly *all* are traced back to their first origin, the closer will their conformity be found to be; the subsequent development of each taking place not only in various degrees, but in different modes or directions; so that the resemblances presented by the higher, at different epochs of their evolution, to the permanent conditions of the lower, are often far from being complete.* This we have seen to be the case in the present instance; the vesicle of the Corpora Quadrigemina, and that of the Third Ventricle, uniting to form the Optic Lobes of Fishes, whilst in the higher Vertebrata they remain distinct; so that there is no single part with which the Optic Lobes can be properly compared, either in the fœtal or perfect state of the Human Brain.

216. The Brain of Reptiles does not show any considerable advance in its general structure above that of Fishes; but the Cerebral hemispheres are usually much larger in proportion to the Optic lobes, whilst the Cerebellum is smaller. The very low development of the Cerebellum is especially seen in the Frog (Fig. 13), in which it is so small, as not even to cover in the Fourth Ventricle; but it is common to nearly the whole group. The deficiency in commissures still exists to a great extent. The Anterior Commissure in front of the third ventricle is the only uniting band which can be distinctly traced in Fishes; and Reptiles have, in addition to this, a layer of uniting fibres which may be compared to the fornix; but as yet, there is no vestige of a true Corpus Callosum, or great transverse commissure of the hemispheres. The distinction between the tubercula quadrigemina, and the parts enclosing the third ventricle, is more obvious than in Fishes; in fact the Optic ganglia of Reptiles correspond pretty closely with the Vesicle of the tubercula quadrigemina in the brain of the fœtal Mammal.

Fig. 19.



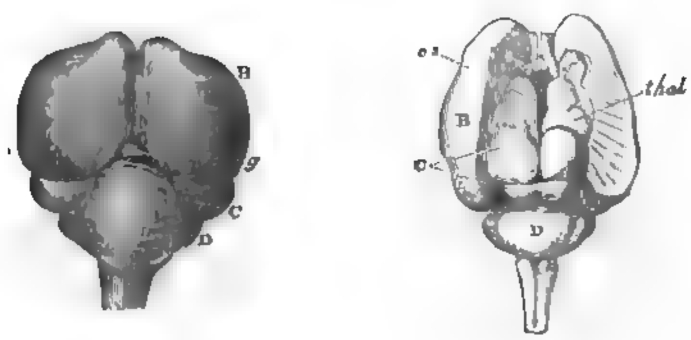
Brain of Turtle; A, olfactive ganglia; B, cerebral hemispheres; C, optic ganglia; D, cerebellum.

217. This is still more evident in Birds, in whose Encephalon the Tubercula Quadrigemina or Optic Ganglia, and the Thalami with their included ventricle, are obviously very distinct parts. In the Bird, the Cerebral Hemispheres attain a great increase of development, and arch backwards, so as partly to cover the Optic ganglia, which are also thrown to one side. The Cerebellum also is much increased in size, proportionably to the Medulla Oblongata and its ganglia; and it is sometimes marked with transverse lines, which indicate the intermixture of grey and white matter in its substance; there is as yet, however, no appearance of a division into hemispheres. On drawing apart the hemispheres of the Cerebrum, the Corpora Striata, Optic Thalami, and Tubercula Quadrigemina or Optic Ganglia, are seen beneath them; the size of the last still bears a considerable proportion to that of the whole Encephalon. The Optic ganglia are still hollow, as they are in the embryo condition of Man. Indeed the Brain of the Human fœtus about the twelfth week will bear comparison, in many respects, with that of the Bird.

* For a full examination of this interesting question, see General and Comparative Physiology, § 244.

21

Fig. 20.

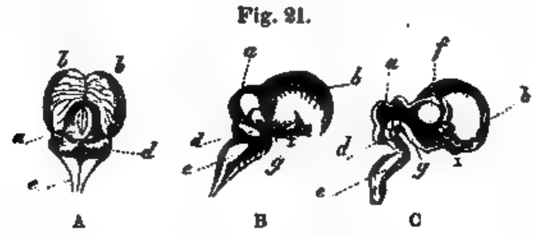


Brain of Buzzard; the olfactive ganglia are concealed beneath B, the hemispheres; C, optic ganglia; D, cerebellum; g.

The hemispheres, B, drawn to either side, to show the subjacent parts;—C, the optic lobes; D, corpus striatum; *thal*, thalamus opticus.

The Cerebral hemispheres, much increased in size, and arching back over the Thalami and Optic ganglia, but destitute of convolutions and deficient in commissures,—the large cavity still existing in the Optic ganglia, and freely communicating with the third ventricle,—and the imperfect evolution of the Cerebellum,—make the correspondence in the general condition of the two very considerable.

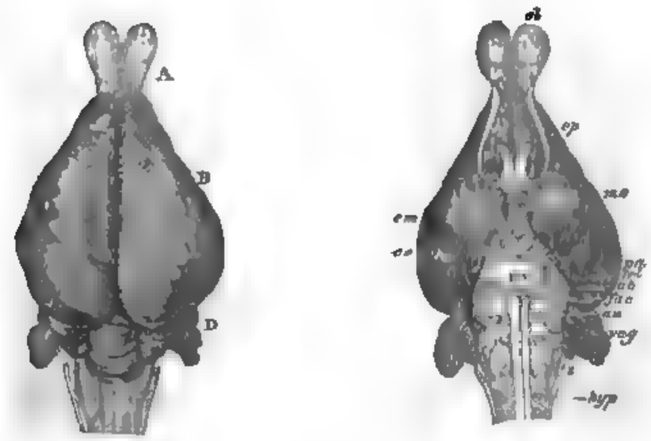
Fig. 21.



Brain of human embryo at twelfth week. A, seen from behind; B, side view; C, sectional view; *a*, corpora quadrigemina; *b*, *b*, hemispheres; *d*, cerebellum; *e*, medulla oblongata; *f*, optic thalamus; *g*, floor of third ventricle; 1, olfactory nerve. (After Tiedemann.)

218. The Brain of the lowest Mammalia presents but a slight advance upon that of Birds, in regard both to the relative proportions of its parts, and to their degree of development. Thus, in the Marsupialia, the Cerebral hemispheres exhibit no convolutions; and the great transverse commissure,—the Corpus Callosum,—is deficient. There is gradually to be noticed, however, in ascending the scale, a backward prolongation of the Cerebral hemispheres; so that first the Optic ganglia, and then the Cerebellum, are covered by them. The latter partly shows itself, however, in all but the Quadrumana, when we look at the brain from above downwards; in the Rabbit, the brain of which is among the lowest in its character of those of the true Viviparous Mammalia, nearly the whole of the Cerebellum is uncovered. In proportion to the increase of the Cerebral hemispheres, there is a diminution in the size of the ganglia immediately connected with the organs of sense; and this in comparison not only with the rest of the Encephalon, but even with the Spinal Cord; so that in Man the tubercula quadrigemina are absolutely smaller than they are in many animals of far

Fig. 29.



Upper and under surface of Brain of Rabbit, A, B, D, as before; *ol*, olfactive lobes; *op*, optic nerve; *mo*, motor oculi; *cm*, corpora mamillaria; *cc*, crus cerebri; *pv*, pons varolii; *pa*, patheticus; *tri*, trifacial; *ab*, abducens; *fac*, facial, *au*, auditory; *vag*, vagus; *s*, spinal accessory; *hyp*, hypoglossal

inferior size. The internal structure of the hemispheres becomes more complex, in the same proportion with their size and the depth of the convolutions; and in Man all these conditions present themselves in a far higher degree than in any other animal. In fact it is only among the Ruminantia, Pachydermata, Carnivora, and Quadrumana, that regular convolutions can be said to exist. The correspondence between the bulbous expansion of the Olfactive Nerves, in Mammalia, and the Olfactive lobes of the lower Vertebrata, is made evident by the presence, in both instances, of a cavity which communicates with the lateral ventricle on each side; it is in Man only that this cavity is wanting. The external form of the Corpora Quadrigemina of Mammalia differs from that of the Optic ganglia of Birds, owing to the division of the former into anterior and posterior eminences; and there is also an internal difference, occasioned by the contraction of the cavity, which now only remains as the Aqueduct of Sylvius. The Cerebellum is chiefly remarkable for the development of its lateral parts or hemispheres; the central portion, sometimes called the vermiform process, is relatively less developed than in the lower Vertebrata, in which it forms the whole of the organ.

Functions of the Cephalic Nerves.

219. Before proceeding to inquire into the functions of the different parts of the Encephalon, it seems desirable to bring together what is known in regard to the functions of the Nerves specially connected with them; so that, by tracing their connections, we may be able to obtain some light upon this very obscure, though most interesting and important subject.

220. That the First pair, or *Olfactory* nerves, minister to the sense of Smell, has long been known; yet it could not be predicated without experimental inquiry, that it is *not* a conductor of the impressions which produce *ordinary* sensation, nor that it is destitute of power of exciting muscular movement, either by direct or reflex action. Although, as we have just now seen, what are commonly regarded as the trunks of the Olfactory

nerves are really the peduncles, by which the bulbous expansions lying on the cribriform plate of the ethmoid bone (in other words, the Olfactory Ganglia) are connected with the rest of the Encephalon and with the Medulla Oblongata,—yet as no other nerves proceed from these ganglia, than those distributed to the Organ of Smell, it is evident that experiments upon what are generally spoken of as the trunks of the Olfactory nerves, will afford information nearly as satisfactory, in regard to the functions of the nerves proceeding from the bulbs, as if they were really so. Anatomical examination of the distribution of this nerve, proves that it is not one which directly conveys motor influence to any muscles; since all its branches are distributed to the membrane lining the nasal cavity. Experimental inquiry leads to the same result; for no irritation of the peduncles or branches excites any muscular movement. Further, no irritation of any part of this nerve excites reflex actions through other nerves. Again, it is not a nerve of common sensation; for animals exhibit no sign of pain when it is subjected to any kind of irritation. Neither the division of the nerve nor the destruction of the olfactive ganglia, seems to inconvenience them materially. They take their food, move with their accustomed agility, and exhibit the usual appetites of their kind. The common sensibility of the parts contained in the olfactive organ is in no degree impaired, as is shown by the effect of irritating vapours; but the animals are destitute of the sense of smell, as is shown by the way in which these vapours affect them. At first they appear indifferent to their presence; and then suddenly and vehemently avoid them, as soon as the Schneiderian membrane becomes irritated. Moreover, if two dogs, with the eyes bandaged, one having the olfactory nerves and ganglia sound, and the other having had them destroyed, are brought into the neighbourhood of the dead body of an animal, the former will examine it by its smell; whilst the latter, even if he touches it, pays no attention to it. This experiment Valentin states that he has repeated several times, and always with the same results. Further, common observation shows that sensibility to irritants, such as snuff, and acuteness of the power of smell, bear no constant proportion to one another; and there is ample pathological evidence, that the want of this sense is connected with some morbid condition of the olfactory nerves or ganglia. It is well known that Magendie has maintained, that the Fifth pair in some way furnishes conditions requisite for the enjoyment of the sense of smell; asserting that, when it is cut, the animal is deprived of this. But his experiments were made with irritating vapours, which excite sternutation or other violent muscular actions, not through the olfactory nerve, but through the fifth pair; and the experiments of Valentin, just related, fully prove that the animals are not sensitive to *odours*, strictly so called, after the Olfactory has been divided. It is by no means improbable, however, that the acuteness of the true sense of smell may be diminished by section of the Fifth pair; since the olfactory membrane is no longer duly moistened by its proper secretion, and, when dry, it is not so susceptible of the impressions made by those minute particles of odoriferous substances, to which the excitement of the sensation must be referred.

221. That the Second pair, or *Optic* nerves, have an analogous character, appears alike from anatomical and experimental evidence. No chemical or mechanical stimulus of the nerve produces *direct* muscular motion; nor does it give rise, so far as can be ascertained, to indications of pain; whence it may be concluded, that this nerve is not one of common sensation. That the ordinary sensibility of the eyeball remains when the functions of the Optic nerve are completely destroyed, is well known; as is also the fact, that division of it puts an end to the power of vision. Valentin states

that, although the Optic nerve may, like other nerves, be in appearance completely regenerated, he has never been able to obtain any evidence that the power of sight has been in the least degree recovered. He remarks that animals suddenly made blind exhibit great mental disturbance, and perform many unaccustomed movements; and that the complete absence of the power of vision is easily ascertained. Morbid changes are sometimes observed to take place in eyes whose Optic nerve has been divided; but these are by no means so constant or so extensive, as when the Fifth pair is paralyzed; and they may not improbably be attributed to the injury occasioned by the operation itself to the parts within the orbit. It is well known that, when amaurosis is produced by a morbid condition of the Optic nerve alone, the eye retains its usual appearance; but, if the amaurosis be complete, the texture of the Retina undergoes a remarkable change, ceasing to exhibit that peculiar structure which normally characterizes it. Neither primitive nervous fibrils, nor nucleated globules, can be distinguished in it; and the yellow spot of Soemmering becomes paler, and is at last undistinguishable. But if a very slight degree of sensibility to light remain, these changes are much less decided. Further, it is well known that, when the sight is destroyed by a disease or injury which prevents the passage of light through the pupil, the whole eye becomes more or less atrophied; and the Retina and Optic nerve, although previously sound, are found after death (if the morbid condition have lasted sufficiently long) to have lost their characteristic structure. It seems evident, then, that the continuance of the functional operations of nerves, is a necessary condition of the maintenance of their normal organization; and we can very well understand that this should be the case, from the analogy of other parts of the system.

222. The Optic nerve, though analogous to the Olfactory in all the points hitherto mentioned, differs from it in one important respect;—that it has the power of conveying impressions which shall excite *reflex* muscular motions. This is especially the case in regard to the Iris, the ordinary actions of which are regulated by the degree of light impinging on the retina. When the optic nerve is divided, a contraction of the pupil takes place; but this does not occur if the connection of this nerve with the third pair, through the nervous centres, be in any way interrupted. After such division (if complete), the state of the pupil is not affected by variations in the degree of light impinging on the retina, except in particular cases in which it is influenced through other channels. Thus, in a patient suffering under amaurosis of one eye, the pupil of the affected eye is often found to vary in size in accordance with that of the other eye; but this effect is produced by the action of light on the retina of the sound eye, which produces a motor change in the third pair on both sides. Further, as has been formerly stated (§ 205), the *impression* only of light upon the retina may give rise to contraction of the pupil, by reflex action, when the optic nerve is itself sound; whilst no sensations are received through the eye, in consequence of disease in the sensorial portion of the nervous centres. Another cause has been pointed out by Valentin, for the influence of light in causing contraction of the pupil, and *vice versâ;*—that, if the rays impinge upon the iris, a reflex stimulation is produced through the fifth pair; and he remarks that the susceptibility of the iris to this kind of influence seems much increased after the optic nerve has been divided. Besides the contractions of the pupil, another action, which has been sometimes spoken of as reflex, is produced through the optic nerve,—the contraction of the orbicularis under the influence of strong light, or when a foreign body is suddenly brought near the eye. But this cannot be produced by any mechanical stimulation, and it

evidently involves *sensation;* in fact, it is a movement of an *emotional* kind, produced by the painful effect of light, which gives rise to the condition well characterized by the term *photophobia.* The involuntary character of it must be evident to every one who has been engaged in the treatment of diseases of the eyes; and the effect of it is aided by a similarly involuntary movement of the eyeball itself, which is rotated upwards and inwards to a greater extent than the will appears able to effect.

223. It will be convenient next to advert to the *Auditory* nerve, or *Portio Mollis* of the Seventh; the functions of which are easily determined, by anatomical examination of its distribution, and by observation of pathological phenomena, to be analogous to those of the two preceding. Atrophy or lesion of the trunk destroys the sense of hearing; whilst irritation of it produces auditory sensations, but does not occasion pain. From experiments made upon the nerve before it leaves the cranial cavity, it appears satisfactorily ascertained, that this nerve has no motor power, either of a direct or reflex character, and that it is not endowed with common sensibility. It is interesting to remark, that microscopic examination of its structure clearly indicates its intermediate character, between the nerves of special sensation issuing from the anterior part of the cranium,—namely, the Optic and Olfactory,—and those whose function is to minister, either to common sensation, or to that of taste which approaches nearly to it,—namely, the Fifth pair and the Glosso-pharyngeal,—which issue from the posterior part of the Encephalon, and are more nearly analogous to the Spinal nerves. The primitive fibres are not so soft as those of the Olfactive, nor so slender as those of the Optic; and they are softer than those of the Glosso-pharyngeal. Moreover, the Auditory nerve forms a plexus with the Facial, to which there is no analogy in the Optic and Olfactive nerves, but to which a similar one exists in the Glosso-pharyngeal. This intermediate structural character is interesting when we compare it with the intermediate character of the function; for the impressions made upon it are produced through vibrations of a material fluid,—instead of being, as in the case of sight, the result of changes so subtle as to be almost inscrutable to our means of research,—or, as in the case of taste and touch, being produced by the direct contact of the substance which gives rise to the sensation.

224. Passing by for the present the Motor nerves of the Orbit, as constituting a distinct subject for future inquiry, we may advantageously proceed with the other Sensory nerves connected with the Encephalon. It should be noticed, however, that the Third pair, or Motor Oculi, certainly possesses some degree of sensibility, as is evidenced by the signs of pain given by the animal when it is cut or compressed; but this sensibility is not nearly so great as that of the Fifth pair; and it may be doubted whether it is possessed by it in virtue of its direct connection with the nervous centres, or whether it does not derive it by its anastomosis with the Fifth pair, some filaments of which may pass backwards as well as forwards, so as to confer sensibility on the Third pair, both before and after their junction with it. No sensory fibres can be proved to exist in the Fourth and Sixth nerves.

225. We next come to the Fifth pair, or *Trifacial,* the true nature of the functions of which was ascertained in part by Sir C. Bell; his views receiving modification, however, from the experimental researches of others. As formerly stated, it possesses two distinct sets of roots, of which one is much larger than the other; on the larger root, as on the posterior root of the spinal nerves, is a distinct ganglion; and the fibres arising from the smaller root do not blend with the others, until after the latter have passed

through this ganglion. The trunk of the nerve separates, as is well known, into three divisions,—The Ophthalmic, the Superior Maxillary, and the Inferior Maxillary; and it can easily be shown by careful dissection, that the fibres of the smaller root pass into the third of these divisions alone. When the distribution of this nerve is carefully examined, it is found that the first and second divisions of it proceed almost entirely to the skin and mucous surfaces, a very small proportion only of its fibres being lost in the muscles; but of the branches of the third division, a large part are distinctly muscular. Hence analogy, and the facts supplied by anatomical research, would lead to the conclusion, that the two first divisions are nerves of sensation only, and that the third division combines sensory and motor endowments. Such an inference is fully borne out by experiment. When the whole trunk is divided within the cranium (as Magendie, by frequent practice, has been able to accomplish), evident signs of acute pain are given. After the incision has been made through the skin, the animal remains quiet until the nerve is touched; and when it is pressed or divided, doleful cries are uttered, which continue for some time, showing the painful effect of the irritated state of the cut extremity. The common sensibility of all the parts supplied by this nerve is entirely destroyed on the affected side. The jaw does not hang loosely, because it is partly kept up by the muscles of the other side; but it falls in a slight degree; and its movements are seen, when carefully observed, to be somewhat oblique. If the trunk be divided on each side, the whole head is deprived of sensibility; and the animal carries it in a curious vacillating manner, as if it were a foreign body.

226. If the anterior or *Ophthalmic* branch only be divided, all the parts supplied by it are found to have lost their sensibility, but their motions are unimpaired; and all experiments and pathological observations concur in attributing to it sensory endowments only. The only apparent exception is in the case of the Naso-Ciliary branch; since there is good reason to believe that the long root of the ciliary ganglion, and the long ciliary nerves, possess motor powers; but these appear to be derived from the Sympathetic nerve. When the whole nerve, or its anterior branch, is divided in the rabbit, the pupil is exceedingly contracted, and remains immovable; but in dogs and pigeons it is dilated. The pupil of the other eye is scarcely affected; or, if its dimensions be changed, it soon returns to its natural state. The eyeball speedily becomes inflamed, however; and the inflammation usually runs on to suppuration and complete disorganization. The commencement of these changes may be commonly noticed within twenty-four hours after the operation; and they appear to be due to the want of the protective secretion, which (as will be explained when the direct influence of the nervous system upon the organic functions is considered) is necessary to keep the mucous surface of the eye in its healthy condition, and which is not formed when the sensibility of that surface is destroyed. The *Superior Maxillary* branch, considered in itself, is equally destitute of motor endowments with the ophthalmic; but its connections with other nerves, through the spheno-palatine ganglion and its anastomosing twigs, may introduce a few motor fibres into it. The *Inferior Maxillary* branch is the only one which possesses motor as well as sensory endowments from its origin; but its different subdivisions possess these endowments in varying proportions, some being almost exclusively motor, and others as completely of a sensory character. The latter is probably the nature of the Lingual branch; and there seems good reason to believe, as will presently be shown, that this ministers not only to the tactile sensibility of the tongue, but to the sense of

taste. The muscles put in action by this branch of the Fifth pair are solely those concerned in the masticatory movements.

227. The *Portio Dura* of the Seventh pair, or *Facial* nerve, has been supposed, since the first researches of Sir C. Bell, to be a nerve of motion only; but some recent physiologists have maintained, that it both possesses sensory endowments, and arises by a double root. The latter assertion is quite fallacious; and the most carefully-conducted experiments do not bear out the former. By exposing the roots of the Seventh pair within the cranium, Valentin ascertained that it possesses no sensory endowments at its origin; since, when these were touched, the animals gave no signs of pain, though violent muscular movements were excited in the face. Subsequently to its first entrance into the canal by which it emerges, however, it anastomoses with other nerves; and thus sensory fibres are introduced into it from many different sources,—anteriorly, from the Fifth pair, and posteriorly, from the Cervical nerves,—which cause irritation of various of its branches to produce pain. The number and situation of the anastomoses vary much in different animals; so that it is impossible to make any very comprehensive statement in regard to them. Experimental researches leave no doubt, that the Portio Dura is the general motor nerve of the face; ministering to the influence of volition and of emotion, and also being the channel of the reflex movements concerned in respiration and other associated movements of the muscles; but not being in the least concerned in the act of mastication.

228. The functions of the *Glosso-Pharyngeal* nerve have been heretofore alluded to in part; but there still remain several questions to be discussed in regard to them. Reasons have been given for the belief that it is chiefly an afferent nerve, scarcely having any *direct* power of exciting muscular contraction, but conveying impressions to the Medulla Oblongata, which produce reflex movements of the other nerves (§ 192). Some experimenters assert, that they have succeeded in exciting direct muscular actions through its trunk. This is by no means impossible; but if the truth of the statement be admitted, it does not invalidate the inferences regarding the *general* function of the nerve, deduced by Dr. Reid from minute anatomical investigation, and from a large number of experiments. Much controversy has taken place on the question, whether this nerve is to be regarded as ministering, partly or exclusively, to the sense of Taste; and many high authorities have ranged themselves on each side. The question involves that of the function of the Lingual branch of the Fifth pair; and it is partly to be decided by the anatomical relations of the two nerves respectively. The glosso-pharyngeal is principally distributed on the mucous surface of the fauces, and on the back of the tongue. According to Valentin, it sends a branch forwards, on either side, somewhat beneath the lateral margin, which supplies the edges and inferior surface of the tip of the tongue, and inosculates with the Lingual branch of the Fifth pair. On the other hand, the upper surface of the front of the tongue is supplied by this lingual branch. The experiments of Dr. Alcock, whose conclusions are borne out by Dr. J. Reid, decidedly support the conclusion, that the gustative sensibility of *this* part of the tongue is due to the latter nerve, being evidently impaired by division of it. Moreover, cases are by no means rare, in which the gustative sensibility of the anterior part of the tongue has been destroyed, with its tactual sensibility; when there was no reason to suppose that any other than the Fifth pair of nerves was involved.* On the other hand, it is equally

* Romberg, in Müller's Archiv. 1838. Heft III.

certain that the sense of taste is not destroyed by section of the Lingual nerve on each side; and it seems also well ascertained that it is impaired by section of the Glosso-pharyngeal nerve. Considering how nearly allied is the sense of taste to that of touch, and bearing in mind the respective distribution of these two nerves, it does not seem difficult to arrive at the conclusion, that both nerves are concerned in this function; but there seems good reason to believe the glosso-pharyngeal to be exclusively that, through which the impressions made by disagreeable substances taken into the mouth are propagated to the Medulla Oblongata, so as to produce nausea and to excite efforts to vomit.

229. The functions of the *Par Vagum* at its roots have lately been made the subject of particular examination by Valentin; and he has arrived at the very interesting result, that it *there* possesses no motor power, but is entirely a sensory or rather an afferent nerve. He states that, if the roots be carefully separated from those of the Glosso-pharyngeal, and (which is a matter of some difficulty) from those of the Spinal Accessory nerve, and be then irritated, no movements of the organs supplied by it can be observed. On the other hand, if the roots be irritated whilst in connection with the nervous centres, muscular contractions, evidently of a reflex character, result from the irritation; and strong evidences of their sensibility are also given. On the other hand, again, when the roots of the Spinal Accessory nerve are irritated, no indications of sensation are given; but the muscular parts supplied by the Par Vagum, as well as by its own trunk, are made to contract, even when the roots are separated from the nervous centres; so that these roots must be regarded as the channel of the motor influence transmitted to them from the Medulla Oblongata. When the Par Vagum swells into the jugular ganglion, an interchange of fibres takes place between it and the Spinal Accessory; but many more fibres can be traced from the latter into the former, than from the former into the latter. Hence it results that, of the branches into which the Par Vagum subsequently divides, many enjoy a high degree of motor power; while those of the Spinal Accessory do not appear to possess any great share of sensibility. The pharyngeal branches are among the most decidedly motor of all those given off from the Pneumogastric; and these may in great part be traced backwards into the Spinal Accessory. Hence the idea of Arnold and Scarpa,—that the Par Vagum and Spinal Accessory are together analogous to a spinal nerve, the former answering to the posterior roots, and the latter to the anterior,—appears sufficiently probable. In regard to its *trunk*, however, the Par Vagum must of course be considered as a nerve of double endowments. The chief function of its afferent portion is to convey to the Medulla Oblongata the impression produced by venous blood in the capillaries of the lungs, or of carbonic acid in the air-cells: this impression may give rise, as we have seen, to the respiratory movements, without producing sensation; but, if it be from any cause stronger than usual, the sense of uneasiness which it occasions is very distressing. This impression may be imitated by pressure on the nerve, which induces an immediate inspiratory movement. That the nerve is capable of conveying those impressions, which become *sensations* when communicated to the sensorium, is further evident from the fact that, when its trunk is pinched, the animal gives signs of acute pain. Besides the pulmonary impressions, this nerve also conveys to the Medulla Oblongata those which originate in the mucous surface of the larynx, trachea, and bronchi, as well as on the lower part of the œsophagus and on the walls of the stomach. The purpose of these is to stimulate various movements, which are performed through the motor por-

tion of the trunk; this excites the actions of the muscles of the pharynx and larynx, of the œsophagus, and, in some degree, of the stomach and respiratory tubes.

230. The section of the Par Vagum produces, as would readily be expected, great disorder of the functions of Respiration and Digestion, to which it ministers. It is an operation which has been very frequently performed; and the statements of its results vary considerably amongst each other, being generally influenced, in some degree, by the preconceived views of the experimenter.* The section of the Par Vagum, when practised with the view of ascertaining the influence of the nerve upon the lungs and stomach, is usually made in the neck, between the origins of the superior and inferior (or recurrent) laryngeal branches. Hence the muscles of the larynx are paralyzed, and, if the animal should struggle violently, the ingress of air is likely to be obstructed by the flapping down of the arytenoid cartilages, and by the closure of the glottis. This is especially the case in young animals, in which the larynx is small. But in those that are full grown, and have a large larynx, an adequate quantity of air may still find its way through the aperture, if the animal refrain from any violent effort. In a considerable number of Dr. Reid's experiments, therefore, he did not find it necessary to introduce the trachea-tube, which other experimenters have generally employed; an opening was made into the trachea, however, in those instances in which, from any cause, the entrance of air was obstructed.

231. The real character of the morbid changes in the lungs, which are induced by cutting the Par Vagum, the order in which they arise, and the causes to which they are immediately due, constitute very interesting subjects of investigation; and the knowledge of them will probably throw light upon many ill-understood morbid phenomena. In the first place, it has been fully established by Dr. Reid, that section of the Vagus on one side only does not necessarily, or even generally, induce disease of that lung; and hence the important inference may be drawn, that the nerve does not exercise any *immediate* influence on its functions. When both Vagi are divided, however, the animal rarely survives long; but its death frequently results from the disorder of the digestive functions. Nevertheless the power of digestion is sometimes restored sufficiently to re-invigorate the animals; and their lives may then be prolonged for a considerable time. In fifteen out of seventeen animals experimented on by Dr. Reid, the lungs were found more or less unfit for the healthy performance of their functions. The most common morbid changes were a congested state of the blood-vessels, and an effusion of frothy serum into the air-cells and bronchial tubes. In eight out of the fifteen, these changes were strongly marked. In some portions of the lungs, the quantity of blood was so great as to render them dense. The degree of congestion varied in different parts of the same lung; but it was generally greatest at the most depending portions. The condensation was generally greater than what could be accounted for by the mere congestion of blood in the vessels, and probably arose from the escape of the solid parts of the blood into the tissue of the lung. In some instances the condensation was so great, that considerable portions of the lung sank in water, and did not crepitate; but they did not present the granulated appearance of the second stage of ordinary pneumonia. In five cases in which the animals

* The Author employs, as in his opinion the most worthy of confidence, the experiments of Dr. J. Reid (Edinb. Med. and Surg. Journ. Vols. XLIX. and LI.) on whose accuracy he has strong personal reasons for placing reliance; and whose anatomical and pathological attainments are such as to render him fully competent to the task.

had survived a considerable time, portions of the lungs exhibited the second, and even the third stages of pneumonia, with puriform effusion in the small bronchial tubes; and in two, gangrene had supervened.

232. One of the most important points to ascertain in an investigation of this kind, is the first departure from a healthy state;—to decide whether the effusion of frothy reddish serum, by interfering with the usual change in the lungs, *causes* the congested state of the pulmonary vessels and the laboured respiration; or whether the effusion is the *effect* of a previously congested state of the blood-vessels. The former is the opinion of many physiologists, who have represented the effusion of serum as a process of morbid secretion, directly resulting from the disorder of that function produced by the section of the nerve; the latter appears the unavoidable inference from the carefully noted results of Dr. Reid's experiments. In several of these, only a very small quantity of frothy serum was found in the air-tubes, even when the lungs were found loaded with blood, and when the respiration before death was very laboured. This naturally leads us to doubt, whether the frothy serum is the cause of the laboured respiration, and of the congested state of the pulmonary vessels, in those cases where it is present; though there can be no doubt that, when once it is effused, it must powerfully tend to increase the difficulty of respiration, and still further to impede the circulation through the lungs. Dr. R. has satisfied himself of an important point, which has been overlooked by others,—that this frothy fluid is not mucus, though it is occasionally mixed with it, but is the frothy serum so frequently found in cases where the circulation through the lungs has been impeded before death. From this and other facts, Dr. R. concludes "that the congestion of the blood-vessels is the first departure from the healthy state of the lung, and that the effusion of frothy serum is a subsequent effect."

233. The next point, therefore, to be inquired into, is the cause of this congestion; and this is most satisfactorily explained, upon the general principles regulating the circulation of the blood, by remembering that section of the Par Vagum greatly diminishes the frequency of the respiratory movements, and that the quantity of air introduced into the lungs is, therefore, very insufficient for the due aeration of the blood. We shall hereafter see reason to regard it as one of the best established principles in Physiology, that the activity of the changes which the blood undergoes in the capillary vessels, does, in some way or other, regulate its movement through them;—that, when these changes are proceeding with activity, the capillary circulation is proportionably accelerated;—and that, when they are abnormally low in degree, the movement of the blood in the capillaries is stagnated. There is now abundant evidence, in regard to the Pulmonary circulation in particular, that to prevent the admission of oxygen in the lungs, either by causing the animal to breathe pure nitrogen or hydrogen, or by occlusion of the air-passages, is to bring the circulation through their capillaries to a speedy check. Hence we should at once be led to infer, that diminution in the number of Respiratory movements would produce the same effect; and as little or no difference in their frequency is produced by section of one Vagus only, the usual absence of morbid changes in the lung supplied by it is fully accounted for. The congestion of the vessels, induced by insufficient aeration, satisfactorily accounts, not only for the effusion of serum, but also for the tendency to pass into the inflammatory condition, sometimes presented by the lungs, as by other organs similarly affected. Dr. Reid confirms this view, by the particulars of cases of disease in the human subject, in which the lungs presented after death a condition similar to that observed

in the lower animals after section of the Vagi; and in these individuals, the respiratory movements had been much less frequent than natural during the latter part of life, owing to a torpid condition of the nervous centres. The opinion (held especially by Dr. Wilson Philip) that section of the par vagum produces the serous effusion by its direct influence on the function of Secretion, is further invalidated by the fact stated by Dr. Reid,—that he always found the bronchial membrane covered with its true mucus, except when inflammation was present.

234. "The experimental history of the Par Vagum," it is justly remarked by Dr. Reid, "furnishes an excellent illustration of the numerous difficulties with which the Physiologist has to contend, from the impossibility of insulating any individual organ from its mutual actions and reactions, when he wishes to examine the order and dependence of its phenomena." In such investigations no useful inference can be drawn from one or two experiments only; in order to avoid all sources of fallacy, a large number must be made; the points in which all agree must be separated from others in which there is a variation of results; and it must be then inquired to what the latter is due. These observations apply equally to the other principal subject of inquiry in regard to the functions of the Par Vagum,—its influence upon the process of Digestion. The results obtained by different experimenters have led to differences of opinion as to its action, no less remarkable than those on the question just discussed. Dr. Wilson Philip has long maintained, that the par vagum controls the secretion of gastric juice, which he stated to cease when the nerve is divided; and he further stated, that the influence of galvanism, propagated along the nerve, would re-establish the secretion. This statement has been quoted and re-quoted, as an established physiological position; and, when united with the well known fact, that galvanism would excite muscular contraction, it has seemed to Dr. W. Philip and other physiologists sufficient to establish the important position, that galvanism and nervous influence are identical. The statement, however, has been disputed by many other experimenters, who have satisfied themselves that the secretion of gastric juice continued, and that the impairment of the digestive power, which is certainly a result (for a time at least) of the operation, may be attributed to paralysis of the muscular coat of the stomach.

235. The experiments of Dr. Reid do not furnish grounds for positive conclusions on the subject; but they furnish important correction of the results obtained by others. He has succeeded, as formerly stated (§ 198), in producing movements of the stomach, by irritation of the Vagi; but that these movements may be excited in other ways, is evident from the fact that, in several of his experiments, food was digested and propelled into the duodenum subsequently to the operation. The same fact, which he appears to have fully substantiated, is an incontrovertible proof, that the secretion of gastric juice is *not dependent* on nervous influence supplied by the Par Vagum, though doubtless in part regulated by it. The first effects of the operation, however, are almost invariably found to be vomiting (in those animals capable of it), loathing of food, and arrestment of the digestive process; and it is not until after four or five days, that the power seems re-established. In the animals which died before that time, no indication of it could be discovered by Dr. R.; in those which survived longer, great emaciation took place; but when life was sufficiently prolonged, the power of assimilation seemed almost completely restored. This was the case in four out of the seventeen dogs experimented on; and the evidence of this restoration consisted in the recovery of flesh and blood by the animals, the vomiting of

half-digested food permanently reddening litmus paper, the disappearance of a considerable quantity of alimentary matter from the intestinal canal, and the existence of chyle in the lacteals. It may serve to account in some degree for the contrary results obtained by other experimenters, to state that seven out of Dr. R.'s seventeen experiments were performed, before he obtained any evidence of digestion after the operation; and that the four which furnished this followed one another almost in succession; so that it is easy to understand why those, who were satisfied with a small number of experiments, should have been led to deny it altogether.

236. It may be hoped, then, that physiologists will cease to adduce the oft-cited experiments of Dr. Wilson Philip, in favour of the hypothesis (for such it must be termed) that secretion is dependent upon nervous influence, and that this is identical with galvanism. Additional evidence of their fallacy is derived from the fact mentioned by Dr. Reid, that the usual mucous secretions of the stomach were always found; and they are further invalidated by the testimony of Müller, who denies that galvanism has any influence in re-establishing the gastric secretion, when it has been checked by section of the nerves. Another series of experiments was performed by Dr. Reid, for the purpose of testing the validity of the results obtained by Sir B. Brodie, relative to the effects of section of the Par Vagum upon the secretions of the stomach, after the introduction of arsenious acid into the system. According to that eminent Surgeon and Physiologist, when the poison was introduced after the Par Vagum had been divided on each side, the quantity of the protective mucous and watery secretions was much less than usual, although obvious marks of inflammation were present. In order to avoid error as much as possible, Dr. Reid made five sets of experiments, employing two dogs in each, as nearly as possible of equal size and strength, introducing the same quantity of the poison into the system of each in the same manner, but cutting the vagi in one, and leaving them entire in the other. This *comparative* mode of experimenting is obviously the only one admissible in such an investigation. Its result was in every instance opposed to the statements of Sir B. Brodie; the quantity of the mucous and watery secretions of the stomach being nearly the same, in each individual of the respective pairs subjected to the experiment; so that they can no longer be referred to the influence of the Eighth pair of nerves. Moreover, the appearances of inflammation were, in four out of the five cases, greatest in the animals whose Vagi were left entire; and this seemed to be referable to the longer duration of their lives after the arsenic had been introduced. The results of Sir B. Brodie's experiments may perhaps be explained, by the speedy occurrence of death in the subjects of them, consequent (it may be) upon the want of sufficiently free respiration, which was carefully guarded against by Dr. Reid.

237. So far as the results of Dr. Reid's experiments may be trusted to, therefore, (and the Author is himself disposed to rely on them almost implicitly,) all the arguments which have been drawn, in favour of the doctrine that secretion depends upon nervous agency, from the effects of lesion of the Vagi upon the functions of the stomach, must be set aside. That this nerve has an important *influence* on the gastric secretion, is evident from the deficiency in its amount soon after the operation, as well as from other facts. But this is a very different proposition from that just alluded to; and the difference has been very happily illustrated by Dr. R. "The movements of a horse," he observes, "are independent of the rider on his back,—in other words, the rider does not furnish the conditions necessary for the

movements of the horse;—but every one knows how much these movements may be influenced by the hand and heel of the rider."

238. It only remains to notice the influence of section of the Vagi upon the actions of the Heart. It has been already stated, that mechanical irritation of these nerves, especially at their roots, has a tendency to excite or accelerate the heart's action. It remains to inquire if its movements are dependent upon their influence, or if they form the channel through which these are effected by emotions of the mind, or by conditions of the bodily system. In regard to the first point, no doubt can be entertained; since the regular movements of the heart are but little affected by section of the Vagi. With respect to the second, there is more difficulty; since the number of causes which may influence the rapidity and pulsations of the heart is very considerable. For example, when the blood is forced on more rapidly towards the heart, as in exercise, struggling, &c., the stimulus to its contractions is more frequently renewed, and they become more frequent; and when the current moves on more slowly, as in a state of rest, their frequency becomes proportionably diminished. If the contractions of the heart were not dependent upon the blood, and their number were not regulated by the quantity flowing into its cavities, very serious and inevitably fatal disturbances of the heart's action would soon take place. That this adjustment does not take place through the medium of the nervous centres, is evident from the fact that, in a dog, in which the par vagum and sympathetic had been divided in the neck on each side, violent struggling, induced by alarm, raised the number of pulsations from 130 to 260 per minute. It is difficult to ascertain, by experiment upon the lower animals, whether simple emotion, unattended with struggling or other exertion, would affect the pulsation of the heart after section of the Vagi; but, when the large proportion of the Sympathetic nerves proceeding to this organ are considered, and when it is also remembered that irritation of the roots of the upper cervical nerves stimulates the action of the heart through the latter, we can scarcely doubt that both may serve as the channels of this influence, especially in such animals as the dog, in which the two freely inosculate in the neck.

239. In regard to the functions of the *Spinal Accessory* nerve, also, there has been great difference of opinion; the peculiarity of its origin and course having led to the belief that some very especial purpose is answered by it. We shall first examine what evidence of its character may be obtained from its anatomy only. Its filaments come off from the middle column of the Spinal Cord, most frequently as low down as the origins of the sixth and seventh Cervical nerves. In its course upwards to the foramen magnum, it lies between the posterior roots of the spinal nerves, and the ligamentum denticulatum. It sometimes receives filaments from these roots, and is generally connected especially with the first cervical; according to Bellingeri, however, who has paid great attention to the subject, the filaments coming from the posterior roots do not form part of the trunk of the nerve, but leave it again to enter the posterior root of the first cervical. It may be doubted whether this is entirely true; as some experiments appear to show that the Spinal Accessory is in some degree a sensory nerve, even at its roots. As the trunk passes through the foramen lacerum, it divides into two branches; of which the internal, after giving off some filaments that assist in forming the pharyngeal branch of the Par Vagum, becomes incorporated with the trunk of that nerve; whilst the external proceeds outwards, and is finally distributed to the sterno-cleido-mastoideus and trapezius muscles, some of its filaments inosculating with those of the cervical plexus. It is interesting to remark, that the junction of the anterior branch with the

Par Vagum beyond the point at which the latter swells out into its superior ganglion, increases the analogy, which has been sustained upon other grounds, between the compound trunk thus formed, and that of the spinal nerves; the Par Vagum being regarded as the sensory root, and the Spinal Accessory as the motor. According to Valentin, however, there is not a mere passage of filaments from the Spinal Accessory to the Par Vagum, but an absolute interchange—the trunk of the former containing some sensory fibres derived from the latter. When the roots of the Spinal Accessory are irritated, as appears from the experiments of Valentin, no decided indications of sensation can be obtained; but all the motor actions of the Par Vagum manifest themselves. When the external branch is irritated, before it perforates the sterno-mastoid muscle, vigorous convulsive movements of that muscle, and of the trapezius, are produced: and the animal does not give any signs of pain, unless the nerve is firmly compressed between the forceps, or is included in a tight ligature. Hence it may be inferred, that the functions of this nerve are chiefly motor, and that its sensory filaments are few in number. Further, when the nerve has been cut across, or firmly tied, irritation of the lower end is attended by the same convulsive movements of the muscles; whilst irritation of the upper end in connection with the spinal cord is unattended with any muscular movement. Hence it is clear that the motions occasioned by irritating it are of a direct, not of a reflex character. The same muscular movements are observed on irritating the nerve in the recently killed animal, as during life.

240. According to Sir C. Bell, the Spinal Accessory is a purely Respiratory nerve, whose office it is to excite the involuntary or automatic movements of the muscles it supplies, which share in the act of respiration; and he states that the division of it paralyzes the muscles to which it is distributed, as muscles of respiration, though they still perform the voluntary movements through the medium of the spinal nerves. Both Valentin and Dr. Reid, however, positively deny that this is the case. Dr. Reid's method of experimenting was well adapted to test the truth of the assertion. Considering that, in the ordinary condition of the animal, it might be difficult to distinguish the actions of particular muscles, beneath the skin, when those in the neighbourhood were in operation; and also that the usual automatic movements might be simulated by voluntary action, when the breathing might be rendered difficult; he adopted the following plan:—A small dose of prussic acid was given to an animal, in which the Spinal Accessory had been previously divided on one side; and after the convulsive movements produced by it had ceased, the animal was generally found in a state similar to that which we sometimes see in apoplexy,—the action of the heart going on, the respirations being slow and heaving, and the sensorial functions appearing to be completely suspended. The Respiratory movements always ceased before the action of the heart; but they continued, in several of the animals experimented on, sufficiently long to allow the muscles of the anterior part of the neck to be laid bare, so that accurate observations could be made upon their contractions. In the dog and cat, the sterno-mastoid does not appear to have much participation in the ordinary movements of respiration; for in several instances it could not be seen to contract on either side, though the head was forcibly pulled towards the chest at each inspiratory movement, chiefly by the action of the sterno-hyoid and thyroid muscles. In two dogs and one cat, however, in which the head was fixed, and these respiratory movements were particularly vigorous, distinct contractions were seen in the exposed sterno-mastoid muscles, synchronous with the other movements of respiration; these were, perhaps, somewhat weaker on

the side on which the nerve had been cut, but were still decidedly present. In one of these dogs, similar movements were observed in the trapezius, on the side on which the nerve had been divided. As the condition of the animal forbad the idea that volition could be the cause of these movements, it can scarcely be questioned that Sir C. Bell's statement was an erroneous one. As far, therefore, as these experiments afford any positive data in regard to the functions of this nerve, it may be concluded that they are the same as those of the cervical plexus, with which it anastomoses freely. "Future anatomical researches," as Dr. Reid justly remarks, "may perhaps explain to us how it follows this peculiar course, without obliging us to suppose that it has a reference to any special function in the adult of the human species." The study of the history of development has accounted satisfactorily for the peculiar course of the recurrent laryngeal, which may be traced passing *directly* from the par vagum to the larynx, at a time when the neck can scarcely be said to exist, and when that organ is buried in the thorax. As this rises in the neck, the nerve, which at first came off below the great transverse blood-vessels, has both its origin and its termination carried upwards; whilst it is still tied down by these vessels in the middle of its course.

241. The *Hypoglossal* nerve, or *Motor Linguæ*, is the only one which, in the regular order, now remains to be considered. That the distribution of this nerve is restricted to the muscles of the tongue, is a point very easily established by anatomical research; and accordingly we find that, long before the time of Sir C. Bell, Willis spoke of it as the nerve of the motions of articulation, whilst to the Lingual branch of the fifth pair he attributed the power of exercising the sense of taste; and he distinctly stated, that the reason of this organ being supplied with two nerves is its double function. The inference that it is chiefly, if not entirely, a *motor* nerve, which has been founded on its anatomical distribution, is supported also by the nature of its origin, which is usually from a single root, corresponding to the anterior root of the Spinal nerves. Experiment shows that, when the trunk of the nerve is stretched, pinched, or galvanized, violent motions of the whole tongue, even to its tip, are occasioned; and also, that similar movements take place after division of the nerve, when the cut end most distant from the brain is irritated. In regard to the degree in which this nerve possesses sensory properties, there is some difference of opinion amongst physiologists; founded, as it would seem, on a variation in this respect between different animals. Indications of pain are usually given, when the trunk is irritated after its exit from the cranium; but these may proceed from its free anastomosis with the cervical nerves, which not improbably impart sensory fibres to it. But in some Mammalia, the hypoglossal nerve has been found to possess a small posterior root with a ganglion: this is the case in the ox, and also in the rabbit; and in the latter animal, Valentin states that the two trunks pass out from the cranium through separate orifices, and that, after their exit, one may be shown to be sensory, and the other to be motor. Hence this nerve, which is the lowest of those that originate in the cephalic prolongation of the spinal cord generally known as the medulla oblongata, approaches very closely in some animals to the regular type of the spinal nerves; and though in Man it still manifests an irregularity, in having only a single root, yet this irregularity is often shared by the first cervical nerve, which also has sometimes an anterior root only.

242. The Hypoglossal nerve is distributed not merely to the tongue, but to the muscles of the neck which are concerned in the movements of the larynx; and the purpose of this distribution is probably to associate them in

those actions which are necessary for articulate speech. Though *all* the motions of the tongue are performed through the medium of this nerve, yet it would appear, from pathological phenomena, to have at least two distinct connections with the nervous centres; for in many cases of paralysis, the masticatory movements of the tongue are but little affected, when the power of articulation is much injured or totally destroyed; and the converse may be occasionally noticed. When this nerve is paralyzed on one side, in hemiplegia, it will be generally observed that the tongue, when the patient is directed to put it out, is projected *towards* the palsied side of the face: this is due to the want of action of the lingual muscles of that side, which do not aid in pushing forwards the tip; the point is consequently directed only by the muscles of the other side, which will not act in a straight direction, when unantagonized by their fellows. It is a curious fact, however, that the hypoglossal nerve seems not to be always palsied on the same side with the facial, but sometimes on the other. This has been suggested to be due to the origination of the roots of this nerve from near the point at which the pyramids of the medulla oblongata decussate; so that some of its fibres come off, like those of the spinal nerves, without crossing; whilst others are transmitted to the opposite side, like those of the higher cerebral nerves; and the cause of paralysis may affect one or other of these sets of roots more particularly. Whatever may be the validity of this explanation, the circumstance is an interesting one, and well worthy of attention.*

243. The character of the Cephalic nerves as distinguished from the Spinal, is a point of much interest, when considered in relation to Comparative Anatomy, and to Embryology. It appears, from what has been already stated, that the Par Vagum, Spinal Accessory, Glosso-pharyngeal, and Hypoglossal nerves, may be considered nearly in the light of ordinary Spinal nerves. They all take their origin exclusively in the Medulla Oblongata; and the want of correspondence in position between their roots and those of the Spinal nerves is readily accounted for, by the alteration in the direction of the columns of the Spinal Cord, which,—as long since pointed out by Rosenthal, and lately stated prominently by Dr. Reid,—not only decussate laterally, but, as it were, from behind forwards (§ 171). The Hypoglossal, as just stated, not unfrequently possesses a sensory in addition to its motor root. The Glosso-pharyngeal, which is principally an afferent nerve, is stated by Arnold and others to have a small motor root; at any rate, the motor fibres which belong to it are to be found in the Par Vagum. That the Par Vagum and a portion of the Spinal Accessory together make up a spinal nerve, has been already stated as probable. Leaving these nerves out of the question, therefore, we proceed to the rest. Comparative anatomy, and the study of Embryonic development, alike show that the Spinal Cord and Medulla Oblongata constitute the most essential part of the nervous system in Vertebrata; and that the Cerebral Hemispheres are superadded, as it were, to this. At an early period of development, the Encephalon consists chiefly of three vesicles, which correspond with the ganglionic enlargements of the nervous cord of the Articulata, and mark three divisions of the cerebro-spinal axis; and, in accordance with this view, the Osteologist is able to trace in the bones of the cranium, the same ele-

* It may be questioned, however, whether the Hypoglossal is really paralyzed on the opposite side from the facial in such cases. An instance has been communicated to the Author by Dr. W. Budd, in which the hypoglossal nerve was completely divided on one side; and yet the tip of the tongue, when the patient was desired to put it out, was sometimes directed *from* and sometimes *towards* the palsied side; showing that the muscles of either half are sufficient to give any required direction to the whole.

ments which would form three vertebræ, in a much expanded and altered condition. However improbable such an idea might seem, when the cranium of the higher Vertebrata alone is examined, it at once reconciles itself to our reason, when we direct our attention to that of Reptiles and Fishes; in which classes the size of the Cerebral or hemispheric ganglia is very small in comparison with that of the Ganglia of special sensation, and in which the latter evidently form but a continuation of the Spinal Cord, modified in its function; so that, when we trace upwards the cavity of the spinal column into that of the cranium, we encounter no material change, either in its size or direction. The three pairs of nerves of special sensation, make their way out *through* these three cranial vertebræ respectively. At a later period of development, other nerves are interposed *between* these; which, being *intervertebral*, are evidently more analogous to the Spinal nerves, both in situation and function. A separation of the primitive fibres of these takes place, however, during the progress of development, so that their distribution appears irregular. Thus the greater part of the sensory fibres are contained in the large division of the Trigeminus; whilst, of the motor fibres, the anterior ones chiefly pass forwards as the Oculo-motor and Patheticus; and of the posterior, some form the small division of the Trigeminus, and others unite with the first pair from the medulla oblongata, to form the Facial. This last fact explains the close union of this nerve with those proceeding more directly from the medulla oblongata, which we find in Fishes and in some Amphibia. According to Valentin, the Glosso-pharyngeal is the sensory portion of the first pair from the medulla oblongata, of which the motor part is chiefly comprehended in the Facial nerve. It is very interesting to trace this gradual metamorphosis from the character of the Spinal nerves, which is exhibited in the Cephalic, when they are traced upwards from the Medulla Oblongata; and this is shown, as formerly pointed out (§ 223), as much in the nerves of special sensation as in the rest. Although we are accustomed to consider the Fifth pair as *par excellence* the Spinal nerve of the head, the foregoing statements, founded upon the history of its development, show that the nerves of the Orbit really belong to its motor portion; they may consequently be regarded as altogether forming the first of the *intervertebral* or Spinal nerves of the cranium. The Facial and Glosso-pharyngeal appear to constitute the second; whilst the Par Vagum and Spinal Accessory intervene between this and the true spinal, of which the Hypoglossal may be considered as the first.

Motor Nerves of the Orbit.

244. We now return to consider the functions of the *Third*, *Fourth*, and *Sixth* pairs of nerves, together constituting the entire channel of the movements of the eyeball. Their particular functions are but ill understood; and the movements which they govern offer so many peculiarities, that the inquiry becomes a very complex one. It is of peculiar interest, however, both on account of its general bearing on the Physiology of the Nervous System; and at the present time more peculiarly, in consequence of the assistance which a correct knowledge of these functions may afford, in the treatment of Strabismus, by the operation, which has been now so extensively and (when executed with care and judgment) so successfully performed.

245. It will be recollected that, in the Human orbit, six muscles for the movements of the eyeball are found,—the four recti, and the two oblique muscles. The precise actions of these are not easily established by expe-

riment on the lower animals; for in all those which ordinarily maintain the horizontal position, there is an additional muscle, termed the *retractor*, which embraces the whole posterior portion of the globe, and passes backwards to be attached to the bottom of the orbit. This muscle is most developed in Ruminating animals, which, during their whole time of feeding, carry their heads in a dependent position. In most carnivorous animals, instead of the complete hollow muscular cone (the base enclosing the eyeball, whilst the apex surrounds the optic nerve) which we find in the Ruminants, there are four distinct strips, almost resembling a second set of recti muscles, but deep-seated, and inserted into the posterior instead of the anterior portion of the globe. It is obvious that the actions of these must greatly affect the results of any operations we may perform upon the other muscles of the Orbit; and, as it is impossible to divide the former, without completely separating the eye from its attachments, we have no means of correcting such results, but by reason alone. Experiments upon animals of the order Quadrumana, most nearly allied to Man, would be more satisfactory; as in them, the retractor muscle is almost or entirely absent. If the origin and insertion of the four Recti muscles be examined, however, no doubt can remain that each of them, acting singly, is capable of causing the globe to revolve in its own direction,—the superior rectus causing the pupil to turn upwards,—the internal rectus causing it to roll towards the nose,—and so on. A very easy and direct application of the laws of mechanics will further make it evident to us, that the combined action of any two of the Recti muscles will cause the pupil to turn in a direction intermediate between the lines of their single action; and that *any* intermediate position may thus be given to the eyeball by these muscles alone. The fact has not received the attention it deserves; it leads us to perceive that the Oblique muscles must have some supplementary function. It may be objected that this is a theoretical statement only; and that there may be some practical obstacle to the performance of diagonal movements by the Recti muscles, which renders the assistance of the Obliques essential for this purpose. But to this it may be replied, that *no single* muscle can direct the ball either downwards and inwards, or upwards and outwards; and that, as we have good reason to believe *these* movements to be effected by the combination of the Recti muscles, there is no reason why the other diagonal movements should not also be due to them.

246. The action of the *Superior Oblique* muscle has been a matter of dispute. Unlike the other muscles which arise from the back of the orbit, its tendon is not inserted into the front hemisphere of the eye, but into a point behind its vertical axis; and we should, therefore, be led to suppose, that its operation is to move the pupil in a direction contrary to that in which its tendon is inserted;—that is to say, as its tendon passes, from its insertion towards the trochlea, upwards and somewhat inwards, we should suppose that, in shortening, it would draw the back of the eyeball in that direction, and turn the pupil in the contrary one,—namely, downwards and a little outwards. This theory of its action is borne out by experiments both upon the muscle, and the nerve which supplies it; for by laying bare the muscle without disturbing the eyeball or the neighbouring parts, and then exercising gentle traction upon it, so as to draw the tendon in the same manner as ordinary contraction of the muscle would have done, the eyeball is turned downwards and somewhat outwards. The same effect is produced when the Fourth pair of nerves is irritated, either mechanically or by galvanism, after it has been separated from the brain. On the other hand, the Inferior Oblique muscle may be shown, by experiments upon itself, to roll

the eye upwards and inwards; the inward movement is much greater than the outward movement caused by the Superior Oblique; so that these two muscles are not exactly antagonists of each other.

247. The distribution of nerves to these muscles is very peculiar. The Superior Oblique has a nerve for itself alone, namely, the *Fourth* pair; this was formerly called the *Patheticus* nerve, from its being supposed to govern that rotation of the ball upwards and inwards, which gives a pathetic expression to the countenance; but, as just shown, its real action is the reverse. By Sir C. Bell, this nerve was considered as belonging to his Respiratory system; and he endeavoured to show, that the sudden movement of the pupil upwards and inwards, which takes place in coughing and sneezing, and the fixation of the ball in a similar position during sleep, is due to its operation. The ascertained action of the muscle, however, constrained him to suppose, that the operation of the nerve was not to cause contraction but relaxation of this, by which the antagonist muscles might be free to occasion the movement. This idea affords a remarkable exemplification of the degree in which *theory* may, in some minds, usurp the place of observation. There is, as we have formerly seen, no ground for the assumption of a system of Respiratory nerves distinct from those forming the general Excito-Motor system, from which a part of every motor trunk in the body is derived; and the supposition that the *action* of a nerve is ever to cause *relaxation* in a muscle, is at variance with all sound physiological induction. In this particular instance, it is at once refuted, by such experiments on the trunk of the nerve as those just adverted to. It may further be added, in regard to this nerve, that there is no decided reason to believe that it contains any sensory fibres. Its distribution is entirely restricted to the Superior Oblique muscle; but, since in this, as in other muscles of the orbit, there is certainly a degree of sensibility, as is experienced by the fatigue to which the long fixation or violent straining of them gives rise, it may be questioned whether the fourth pair of nerves is entirely motor. Its course within the cranium renders it very unlikely that this point can be satisfactorily determined by experiment. Müller states that a connection exists between this nerve and the ophthalmic branch of the Fifth pair; so that it is not improbable that, as in other instances, its sensory endowments are derived from this source.

248. The same may be said of the *Sixth* pair, which is termed the *Abducens* nerve, from its being solely distributed to the Rectus externus muscle. There is no reason to believe that the actions of either of the two last mentioned nerves are ever involuntary; on the contrary, there will appear reason to suppose that they are, with a branch of the third pair, the sources of the voluntary movements of the eyes. Cases occasionally present themselves, in which this nerve alone is paralyzed; and the outward motion of the ball is then almost entirely lost.

249. The three other Recti muscles, together with the Levator Palpebræ, and Inferior Oblique, are supplied by the Third pair, commonly termed *Oculo-motor*. The general question, how far this nerve is to be regarded as *exclusively motor*, has been already considered (§ 224); that it is *chiefly* so, there can be no doubt. But we have now to inquire, whether there is any ground for believing that different branches of the nerve are subservient to motions of a different character—some, for example, being more connected with the Reflex function of the Spinal Cord; others with that instinctive tendency which causes opposite muscular actions to take place in the two orbits by one effort of the will; and others being immediately directed and controlled by the will. It will be remembered that this nerve subdivides

into two principal branches; of which one supplies the Levator Palpebræ and Superior Rectus; whilst the other is distributed to the Internal and Inferior Recti, and to the Inferior Oblique. Now the action of the former appears to be of a purely voluntary character. We have no instance of the upper lid being elevated by any other than an effort of the will; and, if this be suspended, the Orbicularis may be made to depress it, by the reflexion of a stimulus applied to the edge of the tarsi. Moreover, when a strong light causes the lids to contract involuntarily, we feel conscious that a voluntary effort is required to keep them apart. The same may be said of the directly upward movement of the eyeball, which is caused by the Superior Rectus alone: it is never any thing but a voluntary act; for the upward and inward movement adverted to by Sir C. Bell, is evidently occasioned by the inferior oblique acting alone. On the other hand, it is certain that some, at least, of the actions of the second branch are of a simply reflex nature, and that others cannot be said to be voluntary, but are rather of an instinctive character. It is from this branch that the twigs proceed, which enter the ciliary ganglion, and which govern the movements of the pupil; movements which have been already shown to be of a simply reflex character. Some have attempted to show that the actions of the iris are in a slight degree voluntary, because, by an effort of the will, they could occasion contraction of the pupil; but this so called voluntary contraction is always connected with a change in the place of the eyeball itself, occasioned by an action of some of its muscles. It is principally noticed under the two following conditions. 1. When an object is brought very near the eye, and we steadily fix our attention upon it, the axes of the two eyes are made to converge; and if this convergence be carried to a considerable extent, so that the pupils of both eyes are sensibly directed towards the inner canthus, a contraction of the pupil takes place. The final cause or purpose of this contraction is very evident. When an object is brought near the eye, the rays proceeding from it would enter the pupil (if it remained of its usual size) at an angle of divergence so much greater than that which would allow them to be properly refracted to a focus, that indistinct vision would necessarily result. By the contraction of the pupil, however, the extreme or most divergent rays are cut off, and the pencil is reduced within the proper angle. The principle is precisely the same as that on which the optician applies a *stop* behind his lenses, which reduces their aperture in proportion to the shortness of their focal distance. 2. Contraction of the pupil is also noticed, when the eyeball is performing that rotation upwards and inwards, which has been already spoken of as occasioned by the contraction of the Inferior Oblique muscle; and which, when performed along with violent respiratory actions, or during sleep, must be regarded as involuntary. This rotation also takes place, to a slight degree, when the eyelid is depressed, as in ordinary winking; and it is obvious that in this manner, the surface of the eye is more effectually swept free from impurities which may have gathered upon it, than it would be by the downward motion of the lid alone. But the pupil is *not* contracted when the eyeball is *voluntarily* rotated upwards and inwards,—an action which may be effected by the Superior Rectus, some fibres of which are sufficiently far removed from the central axis of the globe, to give it an internal direction. There is good reason to believe, therefore, that the actions of the *inferior* branch of the Third nerve are in great part *automatic*, whilst those of the *superior* branch are purely *voluntary*. Upon this reasoning, Valentin has founded a very ingenious theory of the *consensual* movements of the eyeball, which will now be explained; and this will be conveniently followed by an inquiry into the nature of this

class of movements, as distinguished from the Reflex on the one hand, and the Volitional on the other.

Consensual Movements.

250. From the foregoing observations it appears, that the Rectus Superior, Obliquus Superior, and Rectus Externus, which are supplied from the superior branch of the Third pair, and by the Fourth and Sixth pairs, are all to be regarded as purely voluntary muscles; and Valentin considers them analogous to the Extensors of the limbs, spine, &c., which are for the most part distinguished by the same character. By the actions of these three muscles, singly or combined, the eyeball may be moved in nearly all directions. On the other hand, the Inferior and Internal Recti, and the Inferior Oblique, supplied by the inferior branch of the Third pair, are more or less automatic in their action; and these are compared, by Valentin, to the flexors. By the single or combined actions of these muscles also, the eyeball may be moved towards almost any point, except in an upward and outward direction; and any one who tries the experiment will find that this is, of all the movements of the eye, the one that is attended with the most constrained action of the muscles.

251. On studying the conjoint movements of the eyeball, we are led to observe the very curious fact, that they are not so much *symmetrical* as *harmonious;* that is to say, the corresponding muscles on the two sides are rarely in action at once; whilst such a harmony or *consent* exists between the actions of the muscles of the two orbits, that they work to one common purpose, namely, the direction of both eyes towards the required object. In order to study them properly, it is necessary to reduce them to some kind of classification. 1. If one eye be rotated *inwards*, and the others *outwards*, the Internal Rectus of one eye, and the External Rectus of the other, are evidently put in action together. This movement is harmonious or consensual, but not symmetrical. 2. *Both* eyeballs are *elevated*, by the contraction of the two Superior Recti. 3. *Both* eyeballs are *depressed;* this is effected by the conjoint action of the Inferior Recti muscles, and the movement is, like the preceding, both harmonic and symmetrical. 4. *Both* are drawn directly *inwards* and *downwards*, as when we look at an object placed on or near the nose; this movement is symmetrical, but not harmonic; and it is effected by the action of the Internal Rectus, joined either with the Inferior Rectus or the Superior Oblique. 5. When one eye is rolled *upwards* and *inwards*, and the other *upwards* and *outwards*, the Inferior Oblique is probably operating on one side, whilst the Superior Rectus unites its action with that of the External on the other. And, 6, when one eye is drawn *downwards* and *inwards*, and the other *downwards* and *outwards*, the Inferior Rectus is probably operating, along with the Internal Rectus, on one side, whilst the Superior Oblique is the chief cause of the latter movement.—All these movements may be voluntarily performed by Man; but it is not so clear that the muscles by which they are effected, are equally influenced by volition in each case; and there are some curious diversities in our power of operating on different muscles, which throw some light on the matter. Of those which are entirely subjected to the will, we can only put that pair in action together, which will operate without destroying the symmetrical position of the two eyes, namely the Superior Recti. We cannot voluntarily abduct both eyes, nor roll them downwards and outwards, by the conjoint action of the two External Recti or Superior Obliques. Nor, again, can we bring any of these voluntary muscles—the Superior

Oblique and Superior Rectus, for example—to act against each other in the two eyes, so as to destroy their symmetry. Thus, as remarked by Valentin, in almost every movement, in which the *harmony* of the two eyes is preserved, whilst the symmetry is destroyed (as in those of the 1st, 5th, and 6th of the foregoing classes), one or more muscles of *voluntary* motion are acting on *one* eye, and one or more of the *automatic* group are chiefly concerned in producing the rotation of the *other*. This idea is an extremely ingenious one, and will be found to be supported by other facts.

252. But there are two kinds of movement of the Eyeballs which are not at all voluntary. In the first of these, *both* eyeballs are rotated *upwards* and *inwards*, by the action of both Inferior Obliques. In the other, *both* eyeballs are directed inwards, by the action of both Internal Recti. Now in both these cases, the *harmony* of the movements is destroyed, but it is by two similar muscles, both acting automatically, and subjected, therefore, to the same stimulus. In the first of these cases, the stimulus may originate in some part very distant from the eye itself, and may be of a purely reflex kind; as when the eye is rotated under the lid, in the acts of sneezing, coughing, winking, &c. The latter we shall find to be another result of the same cause as that which secures the usual harmonic movements of the eyeball (§ 255).

253. It may be stated as a physiological fact, that single vision with two eyes is dependent upon the formation of the image upon parts of the two retinæ, which are *accustomed* thus to act with each other. In many physiological works it is asserted, that single vision is the result of the impressions being made on *corresponding* parts of the two retinæ,—that is to say, on parts equally distant from the axis, on one side or the other: but this seems to be disproved by the fact that patients who have been long affected with Convergent Strabismus, and who see equally well with both eyes (as many do), are not troubled with double vision. On the other hand, when a person whose eyes look straight before him, is the subject of a disorder which renders their motions in any degree irregular, he is at once affected with double vision; and the same has been noticed to be a common immediate result of the successful operation for the cure of strabismus, where vision is good in both eyes. Although the images were previously formed on parts of the retinæ which were very far from corresponding with each other, yet no sooner is the position of the eyes rectified (so that the relation between the situation of the images is the same as it would have been in a sound eye,) than the patient sees double. Now in these cases the difficulty very speedily diminishes, and the patient soon learns to see single. It can scarcely be imagined, then, that to any other cause than *habit*, is to be attributed the long discussed phenomenon of single vision with two eyes. The mind receives the two images, frequently combining them together (as Mr. Wheatstone's ingenious experiments with the Stereoscope have most satisfactorily shown § 339) to produce a picture in relief; and so long as these are conveyed to it in the accustomed manner, it reconciles them together, even if the parts of the retinæ on which they are formed do not correspond; but if any circumstance break this chain, and cause the images to be transmitted to the sensorium through a new channel, the mind requires some little time to adapt itself to this impression, as it does by habit to almost every other.*

* That there is a *greater* tendency to *consent* between the images, when they are formed upon corresponding parts of the retinæ, the Author readily admits; and he thinks that this is a principle of some importance, in explaining the re-adjustment of the eyes, after the operation for Strabismus. Every one who has seen much of this operation is aware, that the re-adjustment of the eye is not always immediate, but

254. If this be admitted, we gain an important step in the explanation of the Consensual movements of the eye. The object to be attained is evidently this—that the *usual* axes of the eye should always be directed towards the object to be viewed; and this, as we have seen, involves the necessity (in a great majority of cases), of unsymmetrical movements being performed by the two eyeballs. Now it is fair to argue from the

that, after the muscle has been freely divided, the eye often remains somewhat inverted for a few days, gradually acquiring its straight position. The Author has known one case in which, after such a degree of temporary inversion as seemed to render the success of the operation very doubtful, eversion actually took place for a short time to a considerable extent; after which the axes became parallel, and have remained so ever since.

Another argument, derived from the results of this operation, in favour of the consensual movement being chiefly dependent upon the place of the impressions on the retina, is, that it is much more successful in those cases, in which the sight of the most displaced eye is good, than in those in which (as not unfrequently happens from long disuse) it is much impaired. In cases of the latter class, the cure is seldom complete. There is one more curious fact which may be adverted to in reference to this subject: that Strabismus not unfrequently arises from the formation of an opaque spot on the centre of the cornea, which prevents the formation of any images on the retina, except by the oblique rays; and nature seems to endeavour (so to speak) to repair the mischief, by causing the eye to assume the position most favourable for the reception of these.

To one more point only, connected with the subject of Strabismus, would the Author now allude. He is well convinced, from repeated observation, that those Surgeons are in the right, who have maintained, in a recent controversy, that, in a large proportion of cases, strabismus is caused by an affection of *both* sets of muscles or nerves, and not of one only; and that it then requires, for its perfect cure, the division of the corresponding muscle on both sides. Cases will be frequently met with, in which this is evident; the two eyes being employed to nearly the same extent, and the patient giving to both a slight inward direction, when desired to look straight forwards. In general, however, one eye usually looks straight forwards, whilst the other is greatly inverted; and the sight of the inverted eye is frequently affected to a considerable degree by disuse; so that, when the patient voluntarily rotates it into its proper axis, his vision with it is far from distinct. Some Surgeons have maintained that the inverted eye is usually the only one in fault, and consider that the division of the tendon of its Internal Rectus is sufficient for the cure. They would even divide its other tendons, if the parallelism be not restored, rather than touch the other eye. The Author is himself satisfied, however, that the restriction of the abnormal state to a single eye, is the exception, and not the rule, in all but very slight cases of strabismus; and to this opinion he is led both by the consideration of the mode in which strabismus first takes place, and by the results of the operations which have come under his notice. If the eyes of an infant affected with cerebral disease be watched, there will frequently be observed in them very irregular movements; the axes of the two being sometimes extremely convergent, and then very divergent. This irregularity is rarely or never seen to be confined to one eye. Now in a large proportion of cases of Strabismus, the malady is a consequence of some cerebral affection during infancy or childhood, which we can scarcely suppose to have affected one eye only. Again, in other instances we find the Strabismus to have resulted from the constant direction of the eyes to very near objects, as in short-sighted persons; and here, too, the cause manifestly affects both. Now it is easy to understand, why one eye of the patient should *appear* to be in its natural position, whilst the other is greatly inverted. The cause of strabismus usually affects the two eyes somewhat unequally, so that one is much more inverted than the other. We will call the least inverted eye A, and the other B. In the ordinary acts of vision, the patient will make most use of the least inverted eye, A, because he can most readily look straight forwards or outwards with it; but to bring it into the axis, or to rotate it outwards, necessitates a still more decided inversion of B. This remains the position of things,—the patient usually looking straight forward with A, which is the eye constantly employed for the purposes of vision,—and frequently almost burying under the inner canthus the other eye, B, the vision in which is of very little use to him. When, therefore, the tendon of the internal rectus of B is divided, the relative position of the two is not entirely rectified. Sometimes it appears to be so for a time; but the strabismus then begins to return, and it can only be checked by division of the tendon of the other eye, A; after which, the cure is generally complete and permanent. That it has not been so in many of the

facts already stated (respecting the distribution of the Third pair, and the known functions of its inferior branch), that, in directing our eyes by a voluntary effort to any particular object, the will acts chiefly upon one eye, and that the other follows its direction by an automatic movement. This automatic movement appears to be governed by the relative place of the images upon the retinæ. It is well known that, in children born blind, the movements are not consensual; they are frequently very far from being so, in cases of congenital cataract, where a considerable amount of light is evidently admitted, but where no distinct image can be formed; and in such cases the movements are most consensual where the object is bright or luminous, and a more vivid impression therefore made upon the retina. It is no objection to this theory to say, that persons who have become blind may still move their eyes in a consensual manner; since, the habit of the association of particular movements having been once acquired, the known laws of nervous action account for its continuance; and, as a matter of fact, a want of consent may be often noticed where the blindness is total. The peculiar vacant appearance which may be noticed in the countenances of persons completely deprived of sight, by amaurotic or other affections which do not alter the external aspect of the eyes, seems to result from this,—that their axes are *parallel*, as if the individual were looking into distant space, instead of presenting that slight convergence, which must always exist between them, when the eyes are fixed upon a definite object. This convergence, which is of course regulated by the Internal Recti, varies in degree according to the distance of the object; and it is astonishing how minute an alteration in the axes of the eyes is perceptible to a person observing them. For instance, A sees the eyes of B directed towards his face, but he perceives that B is *not looking at* him; he knows this by a sort of intuitive interpretation of the fact, that his face is not the point of convergence of B's eyes. But if B, who might have been previously looking at something nearer or more remote than A's face, fix his gaze upon the latter, so that the degree of the convergence of the axis is altered, without the general direction of the eyes being in the least affected, the change is at once perceived by the person so regarded; and the *eyes* of the two then *meet*.

255. The foregoing considerations may be summed up in this simple statement;—that, when the axis of one eye is voluntarily directed towards an object, there is an instinctive tendency on the part of the Nervous System and the muscles by which it acts, to effect a consensual movement of the other, so that *its* accustomed axis also shall be directed towards the object. This principle fully accounts for the only *non-consensual* movement, which can be performed in any way *voluntarily*,—that of *both* eyes *inwards*, or *downwards* and *inwards*, which is effected by the conjoint action of the Internal Recti. Some persons possess the power of performing this to a

cases on which operations have been performed, the Author attributes, without the slightest doubt in his own mind, to the neglect of the second operation. As just now stated, the sight of the most inverted eye is frequently very imperfect; indeed it is sometimes impaired to such an extent, that the patients speak of it as entirely useless. That this impairment results in part from disuse merely, seems very evident, from the great improvement which often succeeds the rectification of the axes. The Author cannot help thinking it probable, however, that the same cause which produced the distortion of the eye may, in some instances at least, have affected the Optic nerve, as well as the Motor nerves of the orbit; and this idea is borne out by the fact of the restoration of sight, in certain cases of Amaurosis, by division of one or more tendons, where no Strabismus previously existed. (See Adams on Muscular Amaurosis.) It is interesting to remark that, in these cases, Strabismus was usually the first effect of the operation; but that the eye generally recovered its ordinary position within a short time, especially when the sight was improving.

much greater degree than others; but in all instances, the eyes must be fixed upon an object; and thus the movement is as referable as any other to this principle. It is, perhaps, desirable to qualify the classification of the nerves and muscles of the Orbit proposed by Valentin, by admitting that *all* have in some degree a voluntary, and in some degree an automatic action; but that voluntary power predominates in regard to one group, whilst the other is more commonly acted on by an automatic impulse. It is clear that the will must have some power over the Inferior Rectus, for example; since both eyes can be voluntarily directed downwards. But the power of the Will over this muscle is much less than it is over the Superior Rectus; as is shown by the fact, that, if we direct the eyes downwards, and then close the lids, no effort of volition can prevent the eye from being rolled upwards by the Inferior Oblique; and that, whilst the lids remain closed, the pupils cannot be directed downwards in any considerable degree. It is evident, then, that the impression of an object upon the retina is almost as necessary to occasion the combined action of the Inferior, as it is to produce that of the Internal Recti. The case is very different in regard to the Superior Recti, which can be made to act together, in any degree, without the necessity of a visual impression.

256. It has been pointed out by Müller as an obvious reason for the separation of the sixth from the third pair of nerves, that there is usually a great tendency to consentient action between the nerves of the two sides, which pass off from the same point of the cerebro-spinal axis,—as we see in the case of Reflex movements of both sides (such as that of the pupil), which are excited by a stimulus applied to one only; and that this holds good also in those movements of the eyes, which are effected by the third pair exclusively,—such as the elevation or depression of both pupils: but in the horizontal movements of the eyeballs, two different actions are being performed on the two sides respectively; and it may be conceived that this may be more readily accomplished by two different nerves, than by branches of the same. We may admit some truth in this idea, without attributing much weight to it. It has been already stated as a result of Embryological research, that all the Nerves of the Orbit do in reality form part of the Spinal nerve, to which the fifth pair alone has been commonly regarded as equivalent; and it is well known that we *can* perform many different actions on the two sides, through the medium of the same nerves, at the same time. It is remarkable, however, that there are some dissimilar movements which it is impossible to execute, with any degree of rapidity, except by long practice: thus, if we move the right hand as if winding on a reel, and afterwards make the left hand revolve in a contrary direction, no difficulty is experienced; but if we attempt to move the two at the same time in contrary directions, we shall find it almost impracticable.

257. There can be no doubt that, in these and many other voluntary movements, we are guided by the *sensations* communicated through the afferent nerves, which indicate to the mind the state of the muscle. Many interesting cases are on record, which show the necessity of this muscular sense for determining voluntary contraction of the muscle. Thus Sir C. Bell (who prominently directed attention to this class of facts under the designation of the *Nervous Circle*) mentions an instance of a woman who was deprived of it in her arms, without losing the motor power; and she stated that she was obliged to keep her eyes constantly fixed on any thing (even her child) which she held in her hands, as she could not continue the muscular effort, when no longer informed, by one sense or the other, that it was necessary. Now the only real difference between the case of the

ordinary muscles, and that of the muscles of the eyeball, is (as Dr. Alison* has justly remarked) that the guiding sensations are those received through the Retina in the latter case, whilst in the former they are those of the muscles themselves. It way be asked in what such *consensual* movements, as those of the Eye, differ from those of a reflex character. The answer is simply, that the former cannot be effected without consciousness, and some mental condition supervening upon it; whilst in the latter, sensation has been shown not to be a necessary link. The former may be as much involuntary as the latter, as is shown in the effects of tickling, which could not be manifested in an unconscious individual; here a condition very much resembling an *emotion* is produced; and from this, as from other emotions, various combined movements may result, with which volition has nothing to do. The same may probably be said of the Instinctive actions of animals, which, as will presently appear, are probably to be referred to the same category with the purely Emotional acts of Man; in both Sensation, and that usually of a special kind, is a necessary link. Further it would appear that actions, which were originally of a completely voluntary character, may come by habit to be performed within the shorter channel; thus a Musician will play a difficult piece whilst keeping up a conversation on an entirely different subject; and here the muscular movements are guided not only by the sensations produced by their own contraction, but also by the anticipation of the auditory sensations which will result from their operation.

Functions of the Encephalon.

258. The portion of the Nervous Centres contained within the cranium, and commonly designated collectively as the *Encephalon*, may be regarded as consisting of three principal divisions:—1, the *Cerebral Hemispheres*, which, in the Mammalia, and especially in Man, constitute by far the largest portion of the whole; 2, the *Cerebellum*, the complete separation of which from the Cerebrum, and its distinct connections with the Medulla Oblongata, mark it out as an organ of peculiar character; and 3, the *Medulla Oblongata*, or cranial prolongation of the Spinal Cord, which is connected at its upper end with the ganglia of special sensation, and with the Thalami optici, which may probably be regarded as the corresponding recipients of ordinary sensory impressions. It has been already shown that the lower part of this is peculiarly connected with the functions of Respiration and Deglutition; and we have now to inquire what special function can be attributed to these ganglionic enlargements at its upper end. That a large number of the actions of the lower animals are immediately prompted by sensations, without the intervention of reasoning processes, is universally admitted; and to these actions the term *Instinctive* is ordinarily given. They appear to result from the direct operation of a mental condition, analogous to that which exists in Man, when the emotions, passions, or propensities are so strongly excited, as to act at once on the body without the intervention of the Will. In the purely reflex movements, it has been shown that sensation is not a necessary link. On the other hand, in Voluntary acts, neither sensations nor emotions *directly* affect the body, but only serve to stimulate the reasoning processes, and to supply motives to the judgment; and the operations of this terminate in the formation of a Volition, the com-

* Anatomical and Physiological Inferences from the Study of the Nerves of the Orbit; in Trans. of Roy. Soc. of Edin. Vol. xv.

mands of which are conveyed to the muscle through a channel structurally distinct, as cases of paralysis fully prove, from that which is the medium of Emotional actions.

259. That many of the lower animals possess psychical endowments, corresponding with those which we term the intellectual powers and moral feelings in Man, cannot be doubted by any person who has attentively studied their characters; but in proportion as these are undeveloped, in that proportion is the animal under the dominion of those Instinctive impulses, which, so far as its own consciousness is concerned, may be designated as blind and aimless, but which are ordained by the Creator for its protection from danger, and the supply of its natural wants. The same may be said of the Human infant, or of the Idiot, in whom the reasoning powers are undeveloped. Instinctive actions may in general be distinguished from those which are the result of voluntary power guided by reason, chiefly by the two following characters:—1. Although, in many cases, experience is required to give the Will command over the muscles concerned in its operations, no experience or education is required, in order that the different actions which result from an Instinctive impulse may follow one another with unerring precision. 2. These actions are always performed by the same species of animal, nearly, if not exactly, in the same manner; presenting no such variation in the means adapted to the object in view, and admitting of no such improvement in the progress of life, or in the succession of ages, as we observe in the habits of individual men, or in the manners and customs of nations, that are adapted to the attainment of any particular ends, by those voluntary efforts which are guided by reason. The fact, too, that these instinctive actions are often seen to be performed under circumstances rendering them nugatory, as reason informs us, for the ends which they are to accomplish (as when the Flesh-fly deposits her egg on the Carrion-plant instead of a piece of meat, or when the Hen sits on a pebble instead of her egg), is an additional proof that the Instinctive actions of animals are prompted, like the consensual movements we have been recently inquiring into, by an impulse which immediately results from a particular sensation being felt, and not by anticipation of the effect which the action will produce.

260. The correspondence between the purely Emotional actions in Man, and those actions in the lower animals to which we give the name of Instinctive, may be made evident by a very simple illustration. The Cuttle-fish is well known to discharge its ink, when pursued, and to tinge the water around with a colour so deep, as to enable it to escape under the cloud thus formed. Now it is not to be supposed that the Cuttle-fish has any notion of the *purpose* which this act will serve; since its constancy and uniformity, and the provision for its performance immediately on the emersion of the young animal from the egg, forbid our regarding it as the result of any act of reasoning. Further, the ink is an excretion which corresponds to the urine (having been found to contain urea); and every one knows how strong an impulse to discharge this is frequently caused by mental emotion. The same may be said of the strongly odorous secretions possessed by many Mammalia, which are discharged under similar circumstances, and evidently with the same object, though of that object the animal itself be not conscious. The *emotion* of fear involuntarily opens the sphincters, and causes the contraction of the receptacle, in one case as in the other: and the great difference in the condition of Man and of the lower animals, in this respect, is simply that, in the former, the purely emotional or instinctive actions are

few in comparison with the whole, whilst in the latter they constitute by far the largest part.

261. Dr. M. Hall is of opinion, that the Spinal System of nerves constitutes the channel of Emotional actions. There is no other evidence for this, however, than the occasional manifestation, in cases of paralysis, of reflex and emotional actions, when voluntary control is lost. Such cases only prove, however, that emotional actions are *not* volitional; they are far from proving them to be Spinal. If the essential correspondence between the purely Emotional acts of Man, and the Instinctive acts of the lower animals be admitted, we may reasonably localize the centre more satisfactorily in that chain of ganglionic masses, which only occupies the centre of the base of the brain in Man, but which, in the lower Vertebrata, possesses an aggregate dimension far exceeding that of the Cerebral hemispheres. We are led to such a localization by a very simple and satisfactory train of reasoning. The actions in question are not simply reflex; since sensation, and something of the nature of emotion, both involving consciousness, are elements in their performance; and, moreover, these sensations are rather of the *special* than of the *common* character, involving, therefore, the olfactory, optic, and auditory ganglia. No intelligent person can doubt, that, as we descend the scale of being, instinct is gradually superseding reason; and that in the lowest Vertebrata (we go no further, because no comparison between the parts of the nervous centres could be made with equal certainty between animals of a different type,) the manifestations of the latter are extremely feeble, nearly all the actions of life being guided by the former. Now on looking at the Encephalon, we perceive a difference in the relative proportions of its principal divisions so closely corresponding with these, that it is difficult to imagine them unconnected. In proportion as we descend the scale, we find the Cerebral Hemispheres diminishing in relative size, whilst the Ganglia at the origins of the nerves of special sensation increase to a remarkable degree; and we cannot, therefore, but consider it probable, that these ganglia and tracts of grey matter, whose size is in Man so trifling in comparison to the bulk of his Cerebral hemispheres, are subservient to those Instinctive actions which are prompted by sensations, but in which volition does not partake.

262. It may be said that, in attributing to this division of the nervous centres a function different from that of the Spinal Cord, on the one hand, and of the Brain, on the other, we are unnecessarily multiplying the systems of nervous fibres which must then be supposed to exist in every trunk;—one, namely, for reflex actions,—another for the instinctive and emotional, and a third for the volitional. But the tendency of Neurological research has certainly been to show, that different functions are performed by the same trunk, in virtue of its containing fibres, which are connected with different divisions of the nervous centres; and knowing, as we do, that these three distinct sources of action have a real existence, it cannot be regarded as improbable, that their channels also should be separate. Those who entertain the idea that different parts of the Cerebral hemispheres perform different offices in the reasoning process (an idea which the Author cannot but regard as probable), can scarcely refuse to admit that the ganglionic matter which lies near the base of these, is likely to have a function quite distinct from that of the convolutions. On turning to the Invertebrata, we find important confirmation of these views in the fact, that, in general, the principal ganglionic masses occupying the place of the Brain of higher animals are closely connected with the organs of special sensation situated in the head, and are therefore analogous to the Optic and other ganglia in Verte-

brata; whilst scarcely any traces can be found of superadded ganglionic bodies at all resembling the Cerebral hemispheres. The almost exclusively Instinctive character of the actions of such animals, harmonizes well with the opinion, that these ganglia are the chief sources of them.

263. The Emotions are concerned in Man, however, in many actions, which are in themselves strictly voluntary. Unless they be strongly excited, so as to get the better of the will, they do not operate directly through the nervous trunks, but are subservient to the intellectual operations, to which they supply materials, or motives. Thus, of two individuals, with differently constituted minds, one shall judge of every thing through the medium of a gloomy morose temper, which, like a darkened glass, represents to his judgment the whole world in league to injure him: and all his determinations, being based upon this erroneous view, exhibit the indications of it in his actions, which are, nevertheless, of an entirely voluntary character. On the other hand, a person of a cheerful, benevolent disposition, looks at the world around as through a Claude Lorraine glass, seeing every thing in its brightest and sunniest aspect; and, with intellectual faculties precisely similar to those of the former individual, he will come to opposite conclusions, because the materials which form the basis of his judgment, are submitted to it in a very different form. Various forms of moral insanity exhibit the same contrast in a yet more striking light. We not unfrequently meet with individuals, still holding their place in society, who are accustomed to act so much upon *feeling*, and to be so little guided by *reason*, as to be scarcely regarded as sane; and a very little exaggeration of such a tendency causes the actions to be so injurious to the individual himself, or to those around him, that restraint is required, although the intellect is in no way disordered, nor are any of the feelings perverted. Not unfrequently we may observe similar inconsistencies, resulting from the habitual indulgence of one particular feeling, or a morbid exaggeration of it. The mother who, through weakness of will, yields to her instinctive fondness for her offspring, in allowing it gratifications which she knows to be injurious to it, is placing herself below the level of many less gifted beings. The habit of yielding to a natural infirmity of temper often leads into paroxysms of ungovernable rage, which, in their turn, pass into a state of maniacal excitement. It is not unfrequently seen that a delusion of the intellect (constituting what is commonly known as Monomania) has in reality resulted from a disordered state of the feelings, which have represented every occurrence in a wrong light tq the mind of the individual. All such conditions are of extreme interest when compared with those which are met with amongst idiots, and animals enjoying a much lower degree of intelligence; for the result is much the same, in whatever way the balance between the feelings and the judgment (which is so beautifully adjusted in the well-ordered mind of Man) is disturbed,—whether by a diminution of the intelligence, or by an exaltation of the feelings. These views will probably be found correct, whatever be the truth of the speculation with which they have been here connected, as to the part of the nervous system concerned in the performance of the purely Emotional actions. That their channel is alike distinct, however, from that of the voluntary movements, and from that of reflex operations, must be apparent to any one who fairly weighs the evidence.

264. The degree in which animals high in the scale of organization can perform the functions of life, without any other centre of action than the Medulla oblongata and Cerebellum, appears extraordinary to those, who are accustomed to regard the Cerebral hemispheres as the centre of all energy. From the experiments of Flourens, Hertwig, Magendie, and

others, it appears that not only Reptiles, but Birds and Mammalia, may survive for many weeks or months (if their physical wants be duly supplied) after the removal of the whole Cerebrum. It is difficult to substantiate the existence in them of actual sensation; but their movements appear to be of a higher kind than those resulting from mere Reflex action. One of the most remarkable phenomena in such a being, is the power of maintaining its equilibrium, which could scarcely exist without consciousness. If it be laid upon the back, it rises again; if pushed, it walks. If a Bird thus mutilated be thrown into the air, it flies; if a Frog be touched, it leaps. Such a being, when violently aroused, has all the manner of an animal waking from sleep; and it manifests just about the same degree of consciousness with a sleeping Man, whose torpor is not too profound to prevent his suffering from an uneasy position, and who moves himself to amend it. The *negative* results of experiments of this kind are much more satisfactory than the positive; that is to say, if we are able to substantiate the performance of a particular function, after the removal of a certain organ, we may be sure that the function is *not* dependent on that organ. But the converse does not hold good; for it frequently happens that, when such violent operations are practised on the nervous centres, they occasion an amount of general disturbance, which suspends or modifies functions that have no immediate connection with the organ in question; so that we cannot safely attribute the alteration in them to the loss of it. For example, Hertwig found that, upon removing the upper part of the hemispheres in a pigeon, the powers of sight and hearing appeared to be destroyed, and the animal sat in one spot, as if asleep; but, being fed during a fortnight, the sensibility returned, and the bird lived for three months.

265. Among the ganglia of special sensation, the functions of the Optic Lobes, or *Corpora Quadrigemina*, have been chiefly examined. The researches of Flourens and Hertwig have shown, that their connection with the visual function, which might be inferred from their anatomical relations, is substantiated by experiment. The partial loss of the ganglion on one side produces partial loss of power and temporary blindness on the opposite side of the body, without necessarily destroying the mobility of the pupil; but the removal of a larger portion, or complete extirpation of it, occasions permanent blindness and immobility of the pupil, with temporary muscular weakness, on the opposite sides. This temporary disorder of the muscular system sometimes manifests itself in a tendency to move on the axis, as if the animal were giddy. No disturbance of consciousness appears to be produced; and Hertwig states that he never witnessed the convulsions, which Flourens mentions as a consequence of the operation, and which were probably occasioned by his incision being carried too deeply.

Functions of the Cerebellum.

266. In regard to the particular purposes which are served by the Cerebellum, physiologists are still much in the dark; although there are not wanting those who consider them well ascertained. That this organ has some special function distinct from that of the Cerebral hemispheres, can scarcely be doubted; since its peculiar structure and position, its independent connections with the Medulla Oblongata, and its extremely variable size relatively to the remainder of the Encephalon, point it out as an instrument adapted to some important purpose. We shall inquire briefly into the nature of the evidence respecting its function, which is supplied to us by Comparative anatomy, by Experiment, and by Pathological phenomena. A Cere-

bellum is found in all Vertebrated animals; although it is in some extremely small, looking like a little prominence on the Medulla Oblongata. When this is the case, it is observed that the whole mass is not a miniature (so to speak) of the large Cerebellum of Man, but that the central portion (termed the vermiform process) is the part most developed; the lobes not presenting themselves, until the organ has acquired an increased dimension. The following table, constructed from materials contained in Serres' most valuable Comparative Anatomy of the Brain, will afford some idea of the materials for speculating on the nature of the function of the Cerebellum, which we obtain from this source. The first column gives the diameter of the Spinal Cord, at the second cervical vertebra; in the two succeeding columns are stated the transverse and the antero-posterior diameters of the Cerebellum; these dimensions are stated in hundred-thousandths of a metre. The fourth column expresses, in round numbers, the proportion which the diameters of the Cerebellum bear to that of the Spinal Cord; the latter being reckoned as 1.

MAMMALIA.	Diam. of Spinal Cord at 2d Cervical Vertebra.	Transverse Diam. of Cerebellum.	Antero-Posterior Diameter of Cerebellum.	Proportions.
Man . . .	1100	12,000	6000	$11 — 5\frac{1}{2}$
Simia Rubra .	900	4500	2443	$5 — 2\frac{1}{2}$
Bear . . .	1300	5900	3500	$4\frac{1}{2} — 2\frac{1}{2}$
Dog . . .	1100	4200	2525	$3\frac{3}{4} — 2\frac{1}{4}$
Dromedary .	1900	7100	4600	$3\frac{3}{4} — 2\frac{1}{2}$
Kangaroo. .	1200	3800	2600	$3\frac{1}{6} — 2\frac{1}{6}$
BIRDS.				
Falcon . .	400	1350	1100	$3\frac{1}{3} — 2\frac{3}{4}$
Swallow . .	3175	500	600	$3 — 3\frac{1}{2}$
Turkey . .	500	1350	1600	$2\frac{2}{3} — 2\frac{1}{5}$
Ostrich . .	700	1750	2500	$2\frac{1}{5} — 3\frac{1}{2}$
REPTILES.				
Crocodile. .	300	500	400	$1\frac{2}{3} — 1\frac{1}{2}$
Frog . . .	300	300	200	$1 — \frac{2}{3}$
FISHES.				
Shark . . .	700	1700	3100	$2\frac{1}{2} — 4\frac{1}{2}$
Cod . . .	575	1350	1700	$2\frac{1}{3} — 3$
Turbot . .	500	750	900	$1\frac{1}{2} — 1\frac{4}{5}$
Lamprey . .	275	225	100	$\frac{4}{5} — \frac{3}{8}$

267. This table affords us much scope for interesting speculation, and may be applied to the correction of hypotheses erected upon other foundations. Before we proceed to these, however, a few general remarks may be made upon it. In the first place, the proportional development of the Cerebellum is seen to be smallest in the Vermiform Fishes, which approach most nearly to the Invertebrata; but it is much greater in the higher Fishes than it is in Reptiles. If we consider in what particular, that may be reasonably supposed to have a connection with this organ, the former surpass

the latter, we should at once be struck with their superiority in activity and *variety* of movement. Passing on to Birds, we remark that its average dimensions greatly surpass those of the organ in Reptiles; but that they do not exceed those occasionally met with in Fishes. The greatest size is not found in the species which approach most nearly to the Mammalia in general conformation, such as the Ostrich; but in those of most active powers of flight. Lastly, on ascending the scale of Mammiferous animals, we cannot but be struck with the rapid advance in proportional size that we observe, as we rise from the lowest, which are surpassed in this respect by many Birds, towards Man, in whom it attains a development which appears enormous when contrasted even with that of the Quadrumana.

268. We have next to inquire what evidence can be drawn from Experimental investigations on the same subject; and in reference to this it is desirable to remark, in the first place, that the experimental mode of inquiry is perhaps more applicable to this organ than to the other parts of the Encephalon, inasmuch as it can be altogether removed with little disturbance of the actions immediately essential to life; and the animals soon recover from the shock of the operation, and seem but little affected, except in some easily-recognized particulars. The principal experimenters upon this subject have been Rolando, Flourens, Magendie, and Hertwig. It is not to be expected that there should be an exact conformity among the results obtained by all. Every one who has been engaged in physiological experiments, is aware of the amount of difference caused by very minute variations in their circumstances; in no department of inquiry is this more the case than in regard to the Nervous system; and such differences are yet more likely to occur in experiments made upon the Nervous Centres, than in those which concern their trunks. The investigations of Flourens are the most clear and decisive in their results; and of these we shall accordingly take a general survey. He found that, when the Cerebellum was mechanically injured, the animals gave no signs of sensibility, nor were they affected with convulsions. When the Cerebellum was being removed by successive slices, the animals became restless, and their movements were irregular; and by the time that the last portion of the organ was cut away, the animals had entirely lost the powers of springing, flying, walking, standing, and preserving their equilibrium,—in short, of performing any combined muscular movements, which are not of a simply-reflex character. When an animal in this state was laid upon the back, it could not recover its former posture; but it fluttered its wings and did not lie in a state of stupor. When placed in the erect position, it staggered and fell like a drunken man,—not, however, without making efforts to maintain its balance. When threatened with a blow, it evidently saw it, and endeavoured to avoid it. It did not seem that the animal had in any degree lost voluntary power over its several muscles; nor did sensation appear to be impaired. The faculty of combining the actions of the muscles in groups, however, was completely destroyed, except so far as those actions (as that of respiration) were dependent only upon the Reflex function of the Spinal Cord. The experiments afforded the same results, when made upon each class of Vertebrated animals; and they have since been repeated, with corresponding effects, by Bouillaud and Hertwig. The latter agrees with Flourens, also, in stating that the removal of the side of the Cerebellum affects the movements of the opposite side of the body; and he further mentions that, if the mutilation of the Cerebellum have been partial only, its function is in great degree restored.

269. All these results are objected to by those who assert that the Cerebellum is the seat of the sexual instinct, on the ground that the ob-

served aberrations of the motor functions are sufficiently accounted for, by the general disturbance which an operation so severe must necessarily induce. The fallacy of this objection, however, is shown by the fact, that the much more severe operation of removing the Hemispheres does not occasion such an aberration; the power of performing the associated movements, and of maintaining the equilibrium, being remarkably preserved after the loss of them.

270. Upon comparing these results with the preceding table, a remarkable correspondence will be observed between them. The classes which have the greatest variety of movements, and which require for them the most perfect combination of a large number of separate muscular actions, have, taken collectively, the largest Cerebellum. Of all classes of Vertebrata, Reptiles are the most inert; and their motions require the least coordination. The active predacious Fishes far surpass them in this respect; and may be compared with Birds in the energy of their passage through the water, and in their facility of changing their direction during the most rapid progression. The Cerebellum, accordingly, bears to the spinal cord in them, very much the same proportion as it does in Birds. On the other hand, the Flat Fish, which lie near the bottom of the ocean, and which have a much less variety of movement, have a very much smaller cerebellum: and the Vermiform Fishes, which are almost or completely destitute of fins, and whose progression is accomplished by flexion of the body, have a Cerebellum so small as to be scarcely discoverable; their motion being, like that of the Articulata, almost entirely of a reflex character, each segment being influenced by its own ganglionic centre, and the Spinal Cord constituting by far the largest proportion of the nervous centres. On looking at the class of Birds, we observe that the active predaceous Falcons, and the swift-winged Swallow (the perfect control possessed by which over their complicated movements every one must have observed), have a cerebellum much larger in proportion, than that of the Gallinaceous birds, whose powers of flight are small, or than that of the Struthious tribe, in which they are altogether absent. Lastly, on comparing its proportional size, in the different orders of Mammalia, with the number and variety of muscular actions requiring combined movements, of which they are respectively capable, we observe an even more remarkable correspondence. In the hoofed Quadrupeds, in which the muscular apparatus of the extremities is reduced to its greatest simplicity, and in which the movements of progression are simple, the Cerebellum is relatively smaller than it is found to be in some Birds; but in proportion as the extremities acquire the power of prehension, and together with this a power of application to a great variety of purposes,—still more, in proportion as the animal becomes capable of maintaining the erect posture, in which a constant muscular exertion, consisting of a number of most elaborately-combined parts, is required,—do we find the size of the Cerebellum, and the complexity of its structure, undergoing a rapid increase. Thus, even between the Dog and the Bear there is a marked difference, the latter being capable of remaining for some time in the erect posture, and often spontaneously assuming it, whilst to the former it is anything but natural. In the semi-erect Apes, again, there is a very great advance in the proportional sixe of the Cerebellum; and those which most approach Man in the tendency to preserve habitually the erect posture, also come nearest to him in the dimensions of this organ. Now it is evident that Man, although far inferior to many of the lower animals in the power of performing various particular kinds of movement, far surpasses them all in the number and variety of the combinations which he is capable of exe-

cuting, and in the complexity of the combinations themselves. Thus, if we attentively consider the act of *walking* in man, we shall find that there is scarcely a muscle of the trunk or extremities which is not actually concerned in it; some being engaged in performing the necessary movements, and others in maintaining the equilibrium of the body, which is disturbed by them. On the other hand, in the Horse or Camel, the muscular movements are individually numerous, but they do not require nearly the same perfect co-ordination. And in the Bird, the number of muscles employed in the movements of flight, and in directing the course of these, is really comparatively small; as may at once be perceived by comparing the rigidity of the skeleton of the trunk of the Bird with that of Man, and by remembering the complete inactivity of the lower extremities during the active condition of the upper. In fact, the motions of the wings are so simple and regular, as to suggest the idea that, as in Insects, their character is more reflex than directly voluntary;—an idea which is supported by the length of time during which they can be kept up without apparent fatigue, and also by the important fact already mentioned, which experimental research has disclosed (§ 264). It is seen, then, that Comparative Anatomy fully confirms the idea which Experimental Physiology suggests, respecting the chief functions of the Cerebellum.

271. Some of Magendie's experiments indicate a further connection of this organ with the motor function, the nature of which is still obscure. This physiologist asserts that, if a wound be inflicted on the Cerebellum, the animal seems compelled by an inward force to retrograde movement, although making an effort to advance; and that, if the Crus Cerebelli on one side be injured, the animal is caused to roll over towards the same side. Sometimes (if Magendie's statements can be relied on), the animals made sixty revolutions in a minute, and continued this movement for a week without cessation. Division of the second Crus Cerebelli restores the equilibrium. Hertwig observed the same phenomenon, when the Pons Varolii (which is nothing more than the commissure of the Cerebellum, surrounding the Crura Cerebri) was injured on one side; and he has also remarked that the movements of the eyes were no longer consensual.

272. On turning to Pathology for evidence of the functions of the Cerebellum, we meet with much that seems contradictory. It must be remembered that a *sudden* effusion of blood, even to a small extent, in *any* part of the Encephalon, is liable to produce the phenomena of apoplexy or paralysis; and inferences founded upon the phenomena exhibited after sudden lesions of this description are, therefore, much less valid than those based on the results of more chronic affections. In regard to these last, however, it is to be observed, that we are not yet in a condition to be able to state with precision, what amount of morbid alteration in any part of the nervous centres is compatible with but slightly disturbed performance of its function; and that cases are every now and then occurring, which would upset all our previous notions, if we were not aware, that the same difficulty presents itself even in regard to the best established results in Neurology. It is also to be remembered, that the results of disease, occasioning *pressure*, will be peculiarly liable to affect the Medulla oblongata as well as the Cerebellum; and will thus occasion a greater loss of motor power, than would be occasioned by the mere suspension of the function of the latter.

273. Pathological phenomena, when examined with these reservations, appear to coincide with the results of experiment, in supporting the conclusion, that the Cerebellum is not in any way the instrument of *psychical* operations. Inflammation of the membranes covering it, if confined to that

part, does not produce delirium; and its almost complete destruction by gradual softening does not appear necessarily to involve loss of intellectual power. "But," remarks Andral, "whilst the changes of intelligence were variable, inconstant, and of little importance, the lesions of motion, on the contrary, were observed in all the cases [of softening, which had come under his notice] except one; and in this it is not quite certain that motion was not interfered with." In general, apoplexy of the Cerebellum is accompanied by paralysis; but this is by no means usual in cases of chronic disease, in which there is rather an irregularity of movement, with a degree of restlessness, resembling that described by Flourens as resulting from partial injury of this organ. In a few cases in which both lobes of the Cerebellum have been seriously affected, the tendency to retrograde movement has been observed; and instances are also on record of the occurrence of rotatory movement, which has been found to be connected with lesion of the Crus Cerebelli on the same side. So far as they can be relied on, therefore, the results of the three methods of investigation bear a very close correspondence; and it can scarcely be doubted that they afford us some approximation to truth.

274. We have now to examine, however, another doctrine regarding the functions of the Cerebellum, which was propounded by Gall, and which is supported by the Phrenological school of physiologists. This doctrine—that the Cerebellum is the organ of the sexual instinct—is by no means incompatible with the other; and by some it has been held in combination with it. The greater number of Phrenologists, however, regard this instinct as the *exclusive* function of the Cerebellum, and assert that they can judge of its intensity by the degree of development of the organ. We shall now examine the evidence in support of this position, afforded by the three methods of inquiry which have been already indicated. The results of fair observation as to the comparative size of the Cerebellum in different animals, can scarcely be regarded as otherwise than very unfavourable to the doctrine in question. In the greatest number of Fishes, it is well known that no sexual congress takes place; the seminal fluid being merely effused like any other excretion, into the surrounding water; and being thus brought into accidental contact with the ova, of which a large proportion are never fertilized. On the other hand, in many Reptiles the sexual instinct appears extremely strong; and this is especially the case in the Frog, the whole system of which is endowed, at the season of fertility, with an extraordinary degree of excitability, analogous to a morbid condition that sometimes presents itself in the Human being. It has been remarked that, if the head of a male Frog be cut off, during the congress (which lasts for some time), his embrace will not be relaxed, and will even continue until the body of the female is becoming gangrenous from the pressure; thus showing that the action is one of a purely reflex character. Now, on comparing the size of the Cerebellum of the Frog with that of the Cod, (we exclude the higher Cartilaginous fishes, in which the reproductive function has a more elevated type,) we find that it is not above one-half the proportional size. Moreover, not only is the size much inferior, but the structure is much less complicated, in the former than in the latter. Again, in comparing the Gallinaceous Birds, which are polygamous, with the Raptorial and Insessorial tribes, which live in pairs, we find that the former, instead of having a larger cerebellum, have one of inferior size. Further, on looking at the Mammalia, the same disproportion may be noticed. A friend who kept some kangaroos in his garden, informed the Author that they were the most salacious animals he ever saw; yet their cerebellum is one

of the smallest to be found in the class. Every one knows, again, the salacity of Monkeys; there are many which are excited to violent demonstrations by the sight even of a human female; and there are few which do not practise masturbation, when kept in solitary confinement; yet in them the cerebellum is much smaller than in Man, in whom the sexual impulse is much less violent. It has been supposed that the large size of the organ in Man, is connected with his *constant* possession of the appetite, which is only *occasional* in others; but this does not hold good; since among domestic animals there are many which are ready to breed throughout the year,—Cats and Rabbits, for instance; and in these we do not find any peculiar difference in the size of the Cerebellum. It is asserted, however, that the results of observation in Man lead to a positive conclusion, that the size of the Cerebellum is a measure of the intensity of the sexual instinct in the individual. This assertion has been met by the counter-statement of others,—that no such relation exists. It is unfortunate that here, as in many other instances, each party has registered the observations favourable to their own views, rather than those of an opposite character; so that, until some additional evidence, of a less partial nature, has been collected, we must consider the question as *sub judice*. The Author is by no means disposed to deny that such a correspondence *may* exist; but on contrasting the degree of support which *this* part of phrenology really derives from pathological evidence, with that which the upholders of this view represent it to receive, he cannot but look with much distrust at all their observations on the subject.

275. It is stated in Phrenological works, as an ordinary result of disease of the Cerebellum, that there is an affection of the genital organs, manifesting itself in priapism, turgescence of the testes, and sometimes in seminal emissions. Now it is quite true that, in cases of apoplexy, in which these symptoms manifest themselves, there is very commonly found to be effusion upon the Cerebellum or in its substance; but it is to be remembered, that in all such lesions the Medulla Oblongata is involved, and these symptoms, equally with paralysis, may be due to affection of that organ. Farther, the converse does not by any means hold good; for the proportion of cases of disease of the Cerebellum, in which there is any manifest affection of the sexual organs, is really very small, being, according to the calculations of Burdach, not above *one* in *seventeen*. The same physiologist states that such affections do present themselves, although very rarely, when the Cerebrum is the seat of the lesion. A large number of facts adduced by Phrenologists in support of their views—such as the erections and emissions which often take place during hanging—may be explained as well, or even better, on the hypothesis that the Cerebro-spinal axis (that is, the Spinal cord with the Medulla Oblongata) is the seat of this instinct. And this hypothesis is much more conformable to the results of experiment and disease, than that which locates it in the Cerebellum. For it has been found that mechanical irritation of the Spinal Cord, and disease in its substance, much more frequently produce excitement of the genital organs, than do lesions of the Cerebellum. This view is entertained by Müller, and by most physiologists who have taken a comprehensive and unbiassed survey of the phenomena in question.

276. Among the arguments adduced by Gall and his followers, in proof of the connection between the Cerebellum and the sexual instinct, is one which would deserve great attention, if the facts stated could be relied on. It has been asserted, over and over again, that the Cerebellum, in animals which have been castrated when young, is much smaller than in those which have retained their virility,—being, in fact, *atrophied* from want of

power to act. Now it is unfortunate that vague assertion, founded on estimates formed by the eye from the cranium alone, is all on which this position rests; and it will be presently shown how very liable to error such an estimate must be. The following is the result of a series of observations on this subject, suggested by M. Leuret,* and carried into effect by M. Lassaigne:—The *weight* of the Cerebellum, both absolutely, and as compared with that of the Cerebrum, was adopted as the standard of comparison. This was ascertained in ten Stallions, of the ages of from nine to seventeen years; in twelve Mares, aged from seven to sixteen years; and in twenty-one Geldings, aged from seven to seventeen years. The average weight of the Cerebrum in the Stallions was 433 *grammes;* the greatest being 485 gr., and the least (which was in a horse of ten years old) being 350. The average weight of the Cerebellum was 61 gr.; the greatest being 65 gr., and the least 56 gr. The average proportion borne by the weight of the Cerebellum to that of the Cerebrum, was, therefore, 1 to 7·07; the highest (resulting from a very small Cerebrum) being 1 to 6·25; and the lowest (resulting from an unusually large Cerebrum) being 1 to 7.46. Throughout it might be observed, that the variation in the size of the Cerebellum was much less than in that of the Cerebrum. In the twelve Mares, the average weight of the Cerebrum was 402 gr.; the highest being 432 gr., and the lowest 336 gr. That of the Cerebellum was 61 gr.; the highest being 66 gr. (which was in the individual with the smallest Cerebrum), and the lowest 58 gr. The average proportion of the weight of the Cerebellum to that of the Cerebrum was 1 to 6·59; the highest being 1 to 5·09, and the lowest 1 to 7. The proportion was, therefore, considerably higher in the perfect female than in the perfect male. In the twenty-one Geldings, the average weight of the Cerebrum was 419 gr.; the highest being 566 gr., and the lowest 346 gr. The average of the Cerebellum was 70 gr.; the highest being 76 gr., and the lowest 64 gr. The average proportion was, therefore, 1 to 5·97; the highest being 1 to 5·16, and the lowest 1 to 7·44. It is curious that this last was in the individual which had the largest Cerebellum of the whole; but the proportional weight of the Cerebrum was still greater.

277. Bringing together the results of these observations, they are found to be quite opposed to the statement of Gall. The weight of the Cerebrum, reckoning the Cerebellum as 1, is thus expressed in each of the foregoing descriptions of animals:—

	Average.	Highest.	Lowest.
Stallions . . .	7·07	7.46	6·25
Mares	6·59	7·00	5·09
Geldings . . .	5·97	7·44	5·16

The average proportional size of the Cerebellum in Geldings, therefore, is so far from being *less* than that which it bears in entire Horses and Mares, that it is positively greater; and this depends not only on diminution in the relative size of the Cerebrum, but on its own larger dimensions, as the following comparison of absolute weights will show:—

	Average.	Highest.	Lowest.
Stallions . . .	61	65	56
Mares	61	66	58
Geldings . . .	70	76	64

The difference is so remarkable, and appears, from examination of the individual results, to be so constant, that it cannot be attributed to any accidental

* Anat. Comp. du Système Nerveux, Tom. i. p. 427.

circumstance, arising out of the small number of animals experimented on. The average weight of the Cerebellum in the ten Stallions and twelve Mares is seen to be the same; and the extremes differ but little in the two; whilst the average in the Gelding is more than one-seventh higher, and the *lowest* is considerably above the *average* of the preceding, while the highest far exceeds the highest among the entire Horses. It is curious that Gall would have been much nearer the truth, if he had said that the dimensions of the *cerebrum* are usually reduced by castration; for it appears from the following table that this is really the case:—

	Average.	Greatest.	Least.
Stallions . . .	433	485	350
Mares	402	432	336
Geldings . . .	419	566	346

The weight of the largest Cerebrum of the Gelding is far above the highest of the Stallions; but it seems to be an extraordinary case, as in no other was the weight above 490 gr. If this one be excluded, the *average* will be reduced still further, being then about 412; this may be seen by looking over the whole table, to give a very fair idea of the usual weight in these animals, which is therefore *less*, by about one-twentieth, than the average of the Stallions. The increased size of the Cerebellum in Geldings may perhaps be accounted for, by remembering that this class of horses is solely employed for its muscular power, and that the constant exercise of the organ is not unlikely to develope its size; whilst Stallions, being kept especially for the purpose of propagation, are much less applied to occupations which call forth their motor faculties.

278. The Author is far from denying *in toto* that any peculiar connection exists between the Cerebellum and the Genital system; but if the evidence at present adduced in support of the Phrenological position be held sufficient to establish it, in defiance of so many opposing considerations, we must bid adieu to all safe reasoning in Physiology. The weight of testimony appears to him to be quite decided, in regard to the connection of the Cerebellum with the regulation of the motor function. How far this invalidates the *moderate* phrenological view, which does not regard the function of the Cerebellum as *exclusively* devoted to the sexual instinct, is a question well deserving of attention. There is nothing opposed to such an idea in the results of the experiments already adverted to (§ 268); since there is no evidence that sexual instinct remained after the removal of the Cerebellum: but, on the other hand, there is no proof that it was destroyed. A circumstance which has been several times mentioned to him, that great application to gymnastic exercises diminishes for a time the sexual vigour, and even totally suspends desire,—seems worthy of consideration in reference to such a view. If the Cerebellum be really connected with both kinds of functions, it does not seem unreasonable, that the excessive employment of it upon one should diminish its energy in regard to the other. Further, it would seem by no means improbable, that the Lobes are specially connected with the regulation and co-ordination of movements; whilst the Vermiform processes, which are very large in many animals in which the former scarcely present themselves, are the parts connected with the sexual function. As an additional argument in favour of the former part of this view, it may be stated, that in Man the lobes bear a larger proportion to the Vermiform processes than in any other animal; and that they undergo their most rapid development during the first few years of life, when a large number of complex voluntary movements are being learned by experience; and associated by means of the muscular sensations accompanying them: whilst

in those animals which have, immediately after birth, the power of regulating their voluntary movements for definite objects, with the greatest precision, the Cerebellum is more fully developed at the time of birth. In both instances it is well formed and in active operation (so far as can be judged by the amount of circulation through it), long before the sexual instinct manifests itself in any perceptible degree.

Functions of the Cerebrum.

279. In regard to certain general positions, there is little difference of opinion amongst Physiologists in reference to this much-controverted subject; and it will be desirable to inquire what may be considered as firmly established, before we proceed with details of a more questionable nature. We shall, as before, apply to Comparative Anatomy, to Experiment, and to Pathology, for our chief data. Any general inferences, founded *only* upon observation of the phenomena presented by Man, must be looked upon with suspicion; since every advance in Comparative Physiology leads us to perceive, how close is the functional relation between organs that are really of analogous nature in different classes of animals. Our first general proposition is, that the Cerebrum is the sole instrument of *Intelligence*,—by which term is implied, the voluntary adaptation of means to ends, in a manner implying a perception of the nature of both. As already pointed out, the actions performed by the lower animals are often such as to leave us in doubt, whether they are the result of a mere instinctive impulse, or of an intelligent adaptation of means to ends; and we are guided in our determination, chiefly by the uniformity of these actions in the several individuals of the same species. If we analyze any of our own instinctive actions, we shall perceive the same absence of design on our own parts, as that which we attribute to the lower animals. No one would assert that the tendency to sexual intercourse is the result of a knowledge of its consequences, and of a voluntary adaptation of means to ends; or that, if we can imagine a man newly coming into the world in the full possession of all his powers, he would wait to eat when hungry; until experience had taught him that the swallowing of food would relieve the uneasy feeling. It has been already shown that, in the infant, the act of sucking may be performed even without a Cerebrum; and for this and other similar actions, therefore, it is doubtful whether consciousness is a requisite condition. Adult animals, whose Cerebral hemispheres have been removed, will eat food that is put into their mouths, although they will not go to seek it; and this is the case with many Human idiots. When the functions of the Brain are disturbed, or in partial abeyance, as in fever, we often see a remarkable return to the instinctive propensities in regard to food; and the Physician frequently derives important guidance as to the patient's diet and regimen (particularly as to the administration of wine), from the inclination or disinclination which he manifests. The *Intelligence* of an animal may be further estimated by its degree of educability,—that is, the facility with which its natural habits may be changed by the influence of Man, and the complication of the mental processes which it appears to perform under its new circumstances. We all know that Insects,—the most active of all Invertebrate animals, are but little susceptible of such influence. It may be doubted whether there ever was a case in which an Insect of any kind could be taught to recognise any one who had been in the habit of feeding it, or to show any other unequivocal mark of intelligence. Bees and other Insects, which display much art in the construction of their habitations, and which

execute a variety of most curious contrivances beautifully adapted to variations in their circumstances, appear to be entirely guided in their operations by instinct; since all Bees act alike under the same circumstances. We do not find one community clever, and another stupid: and for a Bee to be destitute of its peculiar tendency to build at certain angles, would be as remarkable as a Human being without a tendency to eat.* In Insects, as already stated, we can discover little or nothing that is analogous to the Cerebrum of Vertebrata; it is manifest that the cephalic ganglia correspond chiefly with the ganglionic enlargements at the upper end of the Medulla Oblongata, which are connected with the organs of special sensation.

280. On comparing Birds with Insects, we at once see a very remarkable difference in the character of their actions. Their instinctive tendencies are of nearly the same kind; and the usual arts which they exhibit in the construction of their habitations, in procuring their food, and in escaping from danger, must be regarded as instinctive, on account of the uniformity with which they are practised by different individuals of the same species, and the perfection with which they are exercised on the very first occasion. But in the adaption of their operations to peculiar circumstances, Birds display a variety and fertility of resource far surpassing that which is manifested by Insects; and it is not doubted, by those who have attentively observed their habits, that in such adaptations they are often guided by real intelligence. This must be the case, for example, when they make trial of several means, and select that one which best answers the purpose; or when they make an obvious improvement from year to year in the comforts of their dwelling; or when they are influenced in the choice of a situation, by peculiar circumstances, which, in a state of nature, can scarcely be supposed to affect them. The complete domesticability of many Birds is in itself a proof of their possessing a certain degree of intelligence; but this alone does not indicate the possession of more than a very low amount of it; since many of the most domesticable animals are of the humblest intellectual capacity, and seem to become attached to Man, principally as the source on which they depend for the supply of their animal wants. This is the case with most Herbivorous quadrupeds, and with Rabbits, Guinea-pigs, &c.; as well as with the Gallinaceous Birds. The attachment of the Dog or the Elephant is evidently of a much higher kind, and involves a much larger number of considerations; and their actions are evidently the result, in many instances, of a complex train of reasoning, differing in no essential respect from that which Man would perform in similar circumstances. The epithet, "half-reasoning," commonly applied to these animals,

* The only manifestation of educability which the Author has ever noticed, during a pretty long familiarity with the habits of Bees, is the acquirement of a power of distinguishing the entrance of their hive from that of others around. When a swarm is first placed in a new box, and the Bees have gone forth in search of food, they often seem puzzled on their return, as to which is their own habitation; more especially if there be several hives, with similar entrances, in one bee-house; and it has been proposed to paint these entrances of different colours, in order to enable the Bee to distinguish them more readily. In a short time, however, even without such aid, the Bees are seen to dart from a considerable height in the air directly down to their proper entrances; showing that they have *learned* to distinguish these by a memorial power. This the Author has observed most remarkably, in a case in which a hive is placed in the drawing-room of a house, the entrance to it being beneath one of the windows; the adjoining houses have windows precisely similar, except in the absence of this small passage; and he has often noticed that, when a new stock has been placed in this hive, the Bees are some days in learning the exact position of their house, considerably annoying the neighbours by flying in at their windows.

does not express the whole truth; for their mental processes are of the same kind with those of Man, and differ more in the degree of control which the animal possesses over them, than they do in their own character. We have no evidence that any of the lower animals have a voluntary power of guiding, restraining, or accelerating their mental operations, at all similar to that which Man possesses; these seem to be of very much the same character as those which we perform in our dreams, different trains of thought commencing as they are suggested, and proceeding according to the usual laws, until some other disturb them. Although it is customary to regard the Dog and the Elephant as the most intelligent among the lower animals, it is not certain that we do so with justice; for it is very possible that we are misled by that peculiar attachment to Man, which in them must be termed an instinct, and which enters as a motive into a large proportion of their actions; and that, if we were more acquainted with the psychical characters of the higher Quadrumana, we should find in them a greater degree of mental capability than we now attribute to them. One thing is certain,—that, the higher the degree of intelligence which we find characteristic of a particular race, the greater is the degree of variation which we meet with in the characters of individuals; thus every one knows that there are stupid Dogs and clever Dogs, ill-tempered Dogs and good-tempered Dogs, as there are stupid Men and clever Men, ill-tempered Men or good-tempered Men. But no one could distinguish between a stupid Bee and a clever Bee, or between a good-tempered Wasp and an ill-tempered Wasp; simply because all *their* actions are prompted by an unvarying instinct.

281. Before inquiring into the comparative size of the Cerebrum, in different animals, it is desirable to obtain a general notion of its structure. Three principal sets of fibres may be distinguished in the white or medullary substance, of which the great mass of it is composed. These are the Ascending fibres, which proceed from the sensory tract, and diverge from the thalami optici to the periphery; the Descending fibres, which converge from the periphery towards the corpora striata, and then pass downwards into the motor tract; and the Commissural fibres, which establish the connection between the various parts of the periphery and of the substance of the brain. It is on the very large proportion which the commissural fibres bear to the rest, that the bulk of the brain of Man and of the higher animals chiefly depends; and it is easy to conceive, that this condition has an important relation with mental operations, whatever be our view of the functions of different parts of the Brain. The different relative distribution of the gray and white matter in the Cerebrum, from that which is elsewhere presented to us in ganglionic masses, naturally suggests the inquiry, how far this corresponds with what has been stated of their probable functions. It may be remarked, in the first place, that we have no evidence whatever, that the endowments of the fibres are in any degree changed, by passing from the nervous trunks into the Brain; and that it is only where they terminate in the gray substance, that such an alteration takes place in their structure, as to warrant an assumption, in the absence of other evidence, that their function also is altered. The amount of ordinary vascular action in gray substance, as compared with that which takes place in the white, is an important circumstance in favour of the view, that it is the part in which all changes originate, and that the fibrous portion, like the trunk of the nerve, serves only to conduct or transmit the influence of those changes. This position derives additional support from the effects of disease. It has been frequently remarked that, if we compare those cases of cerebral disease in which there is delirium, with those in which it does not occur, we

shall find that it is most common in cases in which there is an inflammatory affection of the surface, or of the membranes,—extending from them into it; whilst, in deep-seated inflammation, the most important symptoms are those which result from sympathetic affections of the muscular system. It has been even proposed to establish a diagnosis between inflammation of the membranes (especially of the arachnoid) and inflammation of the substance of the brain, upon this general fact; but it is to be remembered that (to use the words of Lallemand) "it is impossible that the arachnoid should be inflamed, without the surface of the brain in contact with it being also affected; but its tissue not being altered, there merely results from this vicinity exaltation in its functions." All the cases, therefore, which have been referred to in support of this diagnosis, really tend to establish the proposition, that the superficial portion of the Cerebrum is the part really affected. It is absurd to suppose that inflammation of the membranes, without any abnormal condition of the Brain itself, can seriously affect the mental operations. It has been further remarked that arachnitis of the convexity of the Brain is more frequently attended with delirium and other symptoms of excitement, than similar inflammation affecting the base, in which coma supervenes earlier, with little or no previous disturbance of the intellect: this, too, corresponds with the doctrine just referred to; since the influence of any effusion about the origins of the nerves and the Medulla Oblongata is well known to be prejudicial to their functions as conductors, even entirely suspending them, whilst, from the inferior vascularity of these parts, they are not so liable to manifest symptoms of excitement, from the contiguity of an inflamed membrane. In fact, inflammation of the white substance of the Brain is itself attended rather with a state of torpor, or of partial suspension of its usual operations, than with excitement; irregular convulsive actions are not unfrequently seen, as a result of it; but these are often manifested, when the power of the will over the muscles is destroyed. It may not be difficult to account for this difference of symptoms, by reflecting, that a large proportion of the medullary substance of the Brain consists of a sort of extremely delicate cellular tissue, by which the fibres are connected together, and through which the blood-vessels are distributed; and that it is probably in this that the principal changes take place, of which the early stages of the inflammatory process consist. These changes, being accompanied by turgescence of the vessels, and by effusion into the tissue surrounding them, must occasion a degree of pressure on the enclosed fibres, which shall destroy their conducting power, and shall thus cut off the body from connection with the centre of the intellectual operations; whilst they may at the same time give rise to many irregular and involuntary movements of the muscles, to which the fibres thus affected are distributed.

282. This view is further supported by the researches of Foville on the alterations of the Brain which are connected with insanity. His observations are deserving of great confidence, both for the sake of his own high character and attainments, and on account of the careful manner in which they were made. To avoid trusting to his memory for comparison, Foville has been in the habit of examining the brain of a person who died without any disease in this organ, at the same time with that of one who died insane. In acute cases of Insanity, he frequently found the cineritious portion intensely red, but without adhesion to the membranes; whilst in chronic cases, he found the cortical substance indurated and adherent to the membranes. In nearly all cases of Insanity accompanied with general Paralysis, he has found the white portion of the brain injected and indurated; and he conceives that the fibres had become adherent to each other. It has been sup-

posed by Calmeil that the paralysis of the insane is connected with disease of the cineritious substance; but Foville states that he and his colleagues have made many hundreds of observations on cases, in which there were well-marked alterations of the cortical substance of the brain, without any other manifestations during life than disorder of the intellect. This view is supported by Bouillaud, and by several other eminent pathologists; as is also the other part of the proposition,—that morbid alterations in the medullary portion are connected with disorder in the transmission of motor impulses to the muscles.

283. It is important to bear in mind this induction,—for such we may regard it,—when forming our opinions upon the functions of the Cerebrum in general, or of its several parts, from the various data supplied to us by Comparative Anatomy, and by experimental and pathological inquiry. For in regard to the first of these sources it is to be remarked, that the *size* of the brain does not, considered alone, afford a means of judgment as to its power. The quantity of gray matter on its surface should rather be our guide; and this we may judge of, not only by the depth of the layer, but by the complexity of the convolutions by which the surface is extended. In no class, save in Mammalia, do we find the surface marked with convolutions; and in general we do not meet with that fissure between the hemispheres, which greatly increases the extent of surface. In forming comparisons as to the connection between the size of the Brain, and the intelligence, in different animals, we must not be at all guided by its simple proportional dimensions; since it is very evident that it is rather the proportion of the bulk of the brain to that of the whole body, upon which we should found our comparison. But even this is not altogether a safe guide; and many Physiologists have endeavoured to compare the size of the brain with the aggregate bulk of the nerves proceeding from it. This is a much fairer measure; but it cannot be taken without great difficulty. For all practical purposes, the comparison of the bulk of the Brain with that of the Spinal Cord will probably answer very well. The following table, the materials of which are drawn from Serres' Comparative Anatomy of the Brain, exhibits the three diameters of the Brain of a number of different animals, and the diameter of the Spinal Cord at the second cervical vertebra. The last three columns present, in round numbers, the three diameters of the Brain, reckoning that of the Spinal Cord as 1, for the sake of easy comparison.

	Diameter of Spinal Cord.	DIMENSIONS OF CEREBRUM			Proportional dimensions.		
		Anti-post.	Transv.	Above downw.			
Man	1100	17000	7500	9000	1—16 1/3	1—6 5/6	1—8 1/5
Dolphin	1000	9500	5850	8200	1—9 1/2	1—5 4/5	1—8 1/5
Mandril	950	8100	3200	4900	1—8 1/2	1—3 1/3	1—5
Tiger	1600	9400	4250	6400	1—5 7/8	1—2 5/8	1—4
Dromedary	1900	10500	5050	5800	1—5 1/2	1—2 5/8	1—3
Kangaroo	1200	5300	2350	3800	1—4 2/5	1—2	1—3 1/6
Vulture	800	3200	2200	1550	1—4	1—2 3/4	1—2
Falcon	500	1900	1450	1200	1—3 4/5	1—3	1—2 2/5
Swallow	175	1000	600	550	1—5 5/7	1—3 1/2	1—3 1/7
Pie	450	2000	1400	1200	1—4 2/5	1—3	1—2 2/3
Turkey	500	1750	1250	1200	1—3 1/2	1—2 1/2	1—2 2/5
Parroquet	400	2900	1400	1700	1—7 1/4	1—3 1/2	1—4 1/4
Tortoise	300	1600	500		1—5 1/3	1—1 3/5	
Crocodile	300	800	500		1—2 3/5	1—1 3/5	
Viper	200	600	300		1—2	1—1 1/2	
Frog	300	500	400		1—1 2/3	1—1 1/3	
Shark	700	2300	1100		1—3 1/3	1—1 4/7	
Cod	575	725	800		1—1 1/4	1—1 2/5	
Lamprey	275	400	300		1—1 1/2	1—1 1/4	
Angler	400	400	300		1—1	1—3/4	

284. As might be expected, the Brain of Man bears by far the highest proportion; but this proportion is not so superior in the transverse and vertical diameters, as in the antero-posterior; in fact, in the proportion of the vertical diameter, the brain of Man is equalled by that of the Dolphin, and nearly so in that of the transverse diameter. In the complexity of the convolutions, however, and in the thickness of the gray matter, the Cerebrum of Man far surpasses that of this Cetaceous animal. In these respects the higher Quadrumana present the nearest approach to it; but their brain is much inferior in size. In descending the scale of Mammalia, there may be observed a gradual simplification in the general structure of the Brain, depending upon a great diminution in the amount of commissural fibres; until in the Marsupialia the Brain presents nearly the same condition which it offers in Birds (§ 218). These animals manifest a much lower degree of intelligence than many Birds evidently possess; and it is interesting to remark, that their cerebral hemispheres are proportionably smaller than those which we find in many Birds; the diminution in their relative size not being counterbalanced (as it is in some other instances) by increased complexity of structure. In the class of Birds, we observe that the Vulture and the Falcon, whose predacious instincts give them a considerable amount of general energy, are much inferior in the size of their brains to the Insessorial Birds, which are more intelligent; and that of all there is none in which the Brain is so proportionally large as it is in the Parrot tribe, the educability of which is familiar to every one; whilst the easily-domesticable, but

unintelligent Turkey, has a brain of scarcely half the proportional size. The very small size of the Cerebrum in Reptiles and Fishes completely harmonizes with the same view; these animals presenting for the most part but feeble indications of intelligence. Among Reptiles, the Tortoise has a Cerebrum comparable in length to that of Birds; but its breadth and depth are far less. The largest Cerebra among Fishes are found in the Shark tribe, the superior intelligence of which is well known to those who have had the opportunity of observing their habits; and it is interesting to remark, that their surface occasionally presents an appearance of rudimentary convolutions.

285. Comparative Anatomy, then, fully bears out the general doctrine, that the Cerebrum constitutes the organ of Intelligence, as distinguished from those mere Instincts by which many of the lower animals seem to be almost entirely guided. By Intelligence, we do not mean, however, the reasoning faculties only, but the combination of those powers which are of an educable character, and which become the springs of *voluntary* action in very different proportions in different animals of the same tribe;—as distinct from those which have an immediate relation to the wants of the corporeal system, and which are *automatic* and invariable in the several individuals of the same species. Observation of the Human species exhibits the same distinction. When the Brain is fully developed, it offers innumerable diversities of form and size among various individuals; and there are as many diversities of character. It may be doubted if two individuals were ever exactly alike in this respect. That a Brain which is greatly under the average size, is incapable of performing its proper functions, and that the possessor of it must necessarily be more or less idiotic, there can be no reasonable doubt. On the other hand, that a large well-developed Brain is found to exist in persons who have made themselves conspicuous in the world by their attainments or their achievements, may be stated as a proposition of equal generality? In these opposite cases, we witness most distinctly the antagonism between the instinctive and voluntary powers. Those unfortunate beings, in whom the Brain is but little developed, are guided almost solely by their instinctive tendencies, which frequently manifest themselves with a degree of strength that would not have been supposed to exist; and occasionally new instincts present themselves, of which the Human being is ordinarily regarded as destitute.* On the other hand, those who have obtained most influence over the understandings of others, have always been themselves persons of strong volitional powers, in whom the instinctive tendencies are quite subordinated to the will, and who have given their whole energy to the particular object of their pursuit. It is very different, however, with those who are actuated by what is ordinarily termed *genius*, and whose influence is rather upon the *feelings* than upon the understandings of those around them; these are frequently very deficient in power of even comprehending the ordinary affairs of life; and still more commonly, they show an extreme want of judgment in the management of them, being under the immediate influence of their passions and emotions, and not having brought these under the control of their intelligent will. The life of a *genius*, whether his bent be upon poetry, music, painting, or upon pursuits of a more material character, is seldom one which can be

* A remarkable instance of this has been recently published. A perfectly idiotic girl, in Paris, having been seduced by some miscreant, was delivered of a child without assistance. It was found that she had *gnawed* the umbilical cord in two; in the same manner as is practised by the lower animals. It is scarcely to be supposed that she had any idea of the *object* of this separation.

held up for imitation. In such persons, the *general* power of the mind being low, the Brain is not usually found of any great size. The *mere* comparative size of the Brain, however, affords no accurate measure of the amount of mental power; we not unfrequently meet with men possessing large and well-formed heads; whilst their capacity is not greater than that of others, the dimensions of whose crania have the same general proportion, but are of much less absolute size. Large brains, with deficient activity, are commonly found in persons of what has been termed the *phlegmatic* temperament, in whom the general processes of life seem in a torpid and indolent state; whilst small brains and great activity betoken what are known as the *sanguine* and *nervous* temperaments. These distinctions come to be very important, where we proceed further in our inquiries, and attempt to determine the particular modes of development of the Brain, which coincide with certain manifestations of the mind.

286. Having now inquired into the evidence of the *general* functions of the Cerebrum, which may be derived from examination of its comparative development, we proceed to our other sources of information,—Experiment, and Pathological phenomena. The effects of the entire removal of the Hemispheres have been already described (§ 264). In these and similar experiments, it has been constantly remarked, that injuries of the Cerebral substance do not occasion signs of pain, and that they do not give rise to any convulsive movements. Even the thalami optici and corpora striata may be wounded, without the excitement of convulsions; but if the incisions involve the tubercula quadrigemina, or the medulla oblongata, convulsions uniformly occur. This result perfectly accords with what has been observed in Man; for it has been frequently remarked, when it has been necessary to separate protruded portions of the Brain from the healthy part, that this has given rise to no sensation, even in cases in which the mind has been perfectly clear at the time. The effect of pressure upon the Brain is well known to be the suspension of all its operations: this has been substantiated by experiments upon animals, and also by similar experiments on persons who have had a portion of the cranium removed, so as to expose the membranes of the brain: the presure of the finger upon the membranes occasions a state of immediate unconsciousness, resembling profound sleep, which ceases as soon as the pressure is withdrawn. Such pressure will, of course, affect the whole Encephalon, and not the Cerebrum alone. Experiment does not throw much light on the particular functions of the Corpus Callosum and other Commissures; since they can scarcely be divided without severe general injury. It would appear, however, that the partial or entire absence of these parts, reducing the Cerebrum to the level of that of the Marsupial quadruped or of the Bird, is by no means an unfrequent cause of idiocy.

287. The information afforded by Pathological phenomena is far from being definite. Many instances are on record in which extensive disease has occured in *one* Hemisphere, so as almost entirely to destroy it, without either any obvious injury to the mental powers, or any interruption of the influence of the mind upon the body. But there is no case on record of severe lesion of *both* hemispheres, in which morbid phenomena were not evident during life. It is true that, in Chronic Hydrocephalus, a very remarkable alteration in the condition of the Brain sometimes presents itself, which might *a priori* have been supposed destructive to its power of activity,—the ventricles being so enormously distended with fluid, that the cerebral matter has seemed like a thin lamina, spread over the interior of the enlarged cranium. But there is no proof that absolute destruction

of any part was thus occasioned; and it would seem that the very gradual nature of the change gives to the structure time for accommodating itself to it. This, in fact, is to be noticed in all diseases of the Encephalon. A *sudden* lesion, so trifling as to escape observation, unless this be very carefully conducted, will occasion very severe symptoms; whilst a chronic disease may gradually extend itself without any external manifestation. It will usually be found that sudden paralysis, of which the seat is in the Brain, results from some slight effusion of blood in the substance or neighbourhood of the Corpora Striata; whilst, if it follow disorder of the Brain of long standing, a much greater amount of lesion will usually present itself. In either case, the paralysis occurs in the opposite side of the *body*, as we should expect from the decussation of the pyramids; but it may occur either in the same or on the opposite side of the *face*, the cause of which is not very apparent. If convulsions accompany the paralysis, we may infer that the Corpora Quadrigemina, or the parts below, are involved in the injury; and in this case it is found, that the convulsions are on the affected side of the body. Where, as not unfrequently happens, there is paralysis of one side, accompanying convulsions on the other, it is commonly the result of a lesion affecting the base of the brain and medulla oblongata, on the side on which the convulsions take place. Many apparent anomalies present themselves, however, which are by no means easy of explanation, in the present state of our knowledge.

288. The general result of such investigations is, that the Cerebrum is the organ through which all those impressions are received, which give rise to *voluntary* actions, and that it affords the power of occasioning muscular contraction in obedience to the influence of the will; but that the fibres composing its medullary portion are not susceptible of being thrown into action by mechanical irritation, in the same manner as are those of the Spinal Cord and Nerves,—a peculiarity which may, perhaps, be connected with the slight difference of their structure, formerly explained (§ 110). There is no positive reason for the belief, that the Cerebrum is essential to the purely Emotional actions; and analogy, as we have seen, applied to the explanation of pathological phenomena, would lead to the belief that *their* channel is different. It can scarcely be denied, however, that in the Cerebrum resides that power, by which the attention of the mind is directed to any sensation, and by which, through the medium of a brief reasoning process, a notion is formed regarding its nature: this operation is altogether designated as *perception*,—which term, however, is also applied to its result. Now it will be presently seen, that the formation of such elementary notions in us, is often a complex process, though a rapid one; whilst, in many of the lower animals, it appears to be very much simpler—as to all those points, at least, which concern the instinctive actions necessary for their well-being. Such *intuitive* perceptions occasionally take place in ourselves; but it will probably appear, from examination of them, that they are connected either with the mere Instincts, or with the Emotions.

289. Some metaphysicians have confounded *Perception* with *Sensation*; but the difference may be easily made evident. In order that a *sensation* should be produced, a *conscious* state of the mind is all that is required. Its whole attention may be directed towards some other object, and the sensation calls up no new ideas whatever; yet it will produce some change in the sensorium, which causes it to be (as it were) registered there for a time, and may become the object of subsequent attention; so that, when the mind is directed towards it, that idea or notion of the cause of the sensation is formed, which constitutes a *perception*. For example, a student,

who is directing his thoughts to some object of earnest pursuit, does not receive any intimation of the passage of time from the striking of a clock in his room. The sensation must be produced, if there be no defect in his nervous system; but it is not attended to, because the mind is bent upon another object. It *may* produce so little impression on the mind, as *not* to recur spontaneously, when the train of thought which previously occupied the mind has been closed, and the attention is ready to be directed to any other object; or, the impression having been stronger, it may so recur, and at once excite an idea in the mind. Again, the individual may then be able only to say that he heard the clock strike; or he may be able to retrace the number of strokes. Now, in either case, a simple perception is formed, without his being aware that any mental operation has intervened. He would say that he remembers hearing the clock strike; but this would not express the truth. That which he remembers is a certain series of sonorous impressions, which was conveyed to his mind; and he recognises them as the striking of a clock, by a process in which memory and judgment are combined,—which process may further inform him, that the sounds proceeded from his own particular clock. If he had never heard a clock strike, and the sound produced by it had never been described to him, he would not have been able to form that notion of the object that gave rise to the sensation, which, simple as it appears to be at the time, is the result of complex mental operations. But when these operations have been frequently performed, the perception or notion of the object becomes inseparably connected with the sensation; and thus it is excited by the latter, without any knowledge on the part of the individual that a mental operation has taken place. Such perceptions are termed *acquired*, in contradistinction to the *intuitive* perceptions, of which the lower animals seem to possess a large number. The idea of the distance of an object, for example, is one derived in Man from many sources, and is the result of a long experience; the infant, or the adult seeing for the first time, has to bring the senses of sight and of touch to bear upon one another, in order to obtain it; but, when once the power of determining it is acquired, the steps of the process are lost sight of. In the lower tribes of animals, however, in which the young receive no assistance from their parents, there is an evident necessity for some immediate power of forming this determination; since they would not be able to obtain their food without it. Accordingly they manifest in their actions a perception or governing idea of distances, which can only be gained by Man after long experience. A Fly-catcher, for example, just come out of its shell, has been seen to peck at an insect, with an aim as perfect, as if it had been all its life engaged in learning the art.

290. In some instances, animals learn that by intuitive perception, at which man could only arrive by the most refined processes of reasoning, or by the careful application of the most varied experience. Thus, a little fish, named the *Chætodon rostratus*, is in the habit of ejecting, from its prolonged mout, drops of fluid, which strike insects that happen to be near the surface of the water, and cause them to fall into it, so as to come within its own reach. Now, by the laws of refraction of light, the place of the Insect in the air will not really be what it appears to be to the Fish in the water; but it will be a little below its apparent place, and to this point the aim must be directed. But the difference between the real and the apparent place will not be constant; for the more perpendicularly the rays enter the water, the less will be the variation; and, on the other hand, the more oblique is the direction, the greater will be the difference. Now it is impossible to ima-

gine but that, by an intuitive perception, the real place of the Insect is known to the Fish in every instance, as perfectly as it could be to the most sagacious human mathematician, or to a clever marksman who had learned the requisite allowance in each case by a long experience. In Man, the *acquirement* of perceptions is clearly a cerebral operation; but their *intuitional* formation in the lower animals is probably to be regarded as one of those processes, to which the ganglia connected with the organs of special sense, that are in them of so great a proportional size, are subservient. The same may be said of many of the intuitive perceptions in Man; which, if analyzed, are found to be connected rather with the instinctive and emotional tendencies, than with the intellectual powers,—the perceptions which minister to the exercise of these last, being the result of experience. Thus, it has been well remarked by Dr. Alison, that the changes which Emotions occasion in the countenance, gestures, &c., of one individual, are instinctively interpreted by others; for these signs of mental affection are very early understood by young children, sooner than any associations can be supposed to have been formed, by experience, of their connection with particular modes of conduct; and they affect us more quickly and strongly, and with nicer varieties of feeling, than when it is attempted to convey the same feelings in words, which are signs addressed to the intellect.

291. Many Physiologists and Metaphysicians are of opinion, that *every* sensation actually experienced *may* become the subject of a perception at any future time, though beyond the voluntary power of the memory to retrace; and the phenomena of dreams and delirium, in which these sensations often recur with extraordinary vividness, afford much support to this doctrine. Some of the instances upon record are remarkable, as proving that the sensations may be thus remembered, without any perceptions being attached to them; these sensations having been of such a nature, as not to excite any notion or idea in the mind of the individual. A very extraordinary case of this kind has been recorded, in which a woman, during the delirium of fever, continually repeated sentences in a language unknown to those around her, which proved to be Hebrew and Chaldaic; of these she was perfectly ignorant on her recovery; but on tracing her former history, it was found that, in early life, she had lived as a servant with a clergyman, who had been accustomed to walk up and down the passage, repeating or reading aloud sentences in these languages, which she must have retained in her memory unconsciously to herself. Of the nature of the change by which sensations are thus registered, it is in vain to speculate; and it does not seem likely that we shall ever become acquainted with it. This is certain, however,,—that disease or injury of the brain will destroy this power, or will affect it in various remarkable modes. We not unfrequently meet with cases in which the brain has been weakened by attacks of epilepsy or apoplexy, in such a manner as to prevent the reception of any new impressions; so that the patient does not remember any thing that passes from day to day; whilst the impressions of events, which happened before the commencement of his malady, recur with greater vividness than ever. On the other hand, the memory of the long-since-past is sometimes entirely destroyed; whilst that of events which have happened subsequently to the malady is but little weakened. The memory of particular classes of ideas is frequently destroyed;—that of a certain language, or some branch of science, for example. The loss of the memory of words is another very curious form of this discorder, which is not unfrequently to be met with: the patient understands perfectly well what is said, but is not able to reply in any other terms than *yes* or *no*,—not from any paralysis of the muscles

of articulation, but from the incapability of expressing the ideas in language. Sometimes the memory of a particular class of words only, such as nouns or verbs, is destroyed; or it may be impaired merely, so that the patient mistakes the proper terms, and speaks a most curious jargon. These cases have a peculiar interest, in reference to the final subject of our inquiry.

292. That the different portions of the Cerebrum have different functions in the complex operations of thought, must be admitted to be by no means an improbable speculation; and it is well known that, under the name of Phrenology, or the Science of Mind, a systematic allocation has been made, of what have been regarded as the several fundamental powers and faculties of the mind, to certain parts of the Cerebral hemispheres. This was first attempted by Gall, who states himself to have been guided in his determinations, by observing on the heads of those, who manifested any remarkable faculty or tendency, a corresponding prominence; and to have found confirmation of his inferences, by comparing in like manner the skulls of the lower animals with their peculiar powers and dispositions. Both these branches of inquiry have been taken up by numerous observers; and a large amount of evidence has been adduced by them in support of Gall's views, which appears in itself plausible, and which is regarded by many physiologists of much intelligence as quite decisive. Nevertheless, it does not appear that the doctrine is widely received amongst those, whose peculiar attention to the Physiology and Pathology of the Nervous System give them the highest authority on the subject; and much additional proof would seem to be requisite, before it can take rank as substantially true. It may be freely admitted that Mankind is in the habit of forming an impression of an individual's intellectual capacity, by the height and expansion of his forehead; and that a low forehead and crown, with great development of the occipital portion of the brain, generally accompanies a character in which the influence of the animal passions is predominant; and correspondencies even more detailed may be admitted, without the inference being then conclusive, that these several parts are the distinct organs of the faculties of which we judge by their relative size. It may be thought to be, in regard to the form of the head, very much as in respect to the character of the face,—that we may draw from it a general idea as to the character of the mind, and not unfrequently be able to predicate correctly some minute details; and yet that an attempt to localize the organs more minutely, may be as destitute of truth as were the details of the system of Lavater. Moreover, a fundamental doubt hangs over every determination of function, which results from a comparison of the size of the supposed organ or region in different cases. If it be true that the grey matter only is the source of power, and that the white is merely a conductor, we have no right to assume that the total size of the organ affords a measure of its power, until it has been shown that the thickness of the cortical substance can be judged of by the size of the Brain, or of any part of it. Certainly there is a considerable variation in this respect among different individuals; and it is yet to be proved that the relation is constant in different parts of the same individual Brain. Until this is substantiated, all inferences drawn from correspondence between the prominence of a certain part of the brain, and the intensity of a particular function, are invalid; that is, if the general doctrine of the relative functions of the grey and white matter be true. Moreover, there is unfortunately a considerable uncertainty attending all Phrenological observations which are made upon the cranium, rather than upon the brain; this we have seen from the discrepancy between the statements of Gall, and the facts ascertained regarding the comparative weight of the Cerebellum in

castrated and entire horses. It appears to the Author, too, that Comparative Anatomy and Psychology are very far from supporting the system, when their evidence is fairly weighed.* It is a very curious circumstance, that the difference in the antero-posterior diameter, between the brain of Man and that of the lower Mammalia, principally arises from the shortness of the *posterior* lobes in the latter, these being seldom long enough to cover the Cerebellum; yet it is in these posterior lobes, that the *animal* propensities are regarded by phrenologists as having their seat. On the other hand, the *anterior* lobes, in which the intellectual faculties are considered as residing, bear, in many animals, a much larger proportion to the whole bulk of the brain than they do in Man. Again, Comparative Anatomy and Experiment alike sanction the conclusion, that the purely Instinctive propensities have not their seat in the Cerebrum. These examples, and many similar ones that might easily be added, collectively show the uncertainty, to say the least, of the inferences by many regarded as firmly established.

293. The evidence of Pathology, again, tends to show, that particular disorder of function may result from lesions of any part of the Cerebral hemispheres; this has been especially noticed, for example, in regard to the loss of the memory of words, which Phrenologists locate in the organ of Language: there, of course, the lesion might be expected, on their system, to present itself; but this is by no means constantly, or even generally, the case. Phrenologists lay great stress on the effects of local injury in causing loss of memory of a particular subject; but this principle, if carried to its full extent, would require us to regard each organ as split up into a large number of subdivisions,—the organ of language for example, having one storehouse for Latin; another for Greek, &c.; either of which may be destroyed, without the other being affected. A very important scource of evidence is that afforded by the correspondence between the several kinds of Monomania, and the forms of the brains of the persons exhibiting them; and the number of those who, having studied this question, have given in their adhesion to the phrenological view, is one of the most weighty evidences of its containing much truth. The doubts which have been expressed on the subject would have much less weight, if the coincidence of Phrenological determinations of character, with truth, were more constant. The fairest tests of these are to be found, as Dr. Holland has justly remarked, "not in vague and ill-defined moral propensities, but in a few simple and well-marked faculties, such as those of numerical calculation, languages, or music, which have no others in actual opposition to them, and the degree of perfection in which can be clearly defined." We hear much from Phrenologists, as to their successful application of these tests; but we do not hear of the instances of failure. The Author's own experience of their determinations, however, has certainly led him to the belief, that failure is nearly as frequent as success. Without wishing to set himself up as an opponent to Phrenology, he perfectly agrees with Dr. Holland in thinking, that an impartial view of it requires, "not that the doctrine should be put aside altogether, but that great abatement should be made of its pretensions as a system." In par-

* Much is said by Phrenologists respecting M. Vimont's examination of the question, and of the affirmative decision to which he has come; but they are not ready to mention, that M. Leuret, from at least equally extensive observations, has arrived at an opposite conclusion. Of these two, if authority is to decide the matter, the Author would certainly give the preference to M. Leuret, as a man of general eminence, and one who had a reputation to lose; whilst M. Vimont was previously unknown, and has only brought himself into notoriety by his advocacy of Phrenology.

ticular, he thinks that those who pursue it, are bound to make themselves first acquainted with what can be established as the general functions of the Brain, before descending to particulars.

General Recapitulation and Pathological Applications.

294. A general Summary of the views here propounded, in regard to the Functions of the Cerebro-Spinal division of the Nervous system, may probably be useful in assisting the Student to gain clear ideas regarding them.—The fibres of the nervous trunks may be divided, according to the direction of their influence, into two classes,—the *afferent* or *centripetal*,—and the *efferent* or *centrifugal*. The afferent may be said to commence at the periphery, especially on the skin, mucous surfaces, &c., and to terminate in the grey matter of the nervous centres; whilst the efferent originate in that grey matter, and terminate in the muscles.* Every fibre runs a distinct course from its origin to its termination; and it is not improbable that the endowments of the different fibres composing each trunk are very distinct. From the great vascularity of the grey matter, and the occurrence of a structure of corresponding character around the origins of the afferent nerves, it is evident that its functions must be different from those of the fibrous structure; and, whilst there is no evidence that the latter serves any different purpose than that of a mere conductor, there seems good reason to believe that all the active operations, of which the nervous system is the instrument, originate in the former. A mass of grey matter connected with nervous trunks, forms a *ganglion;* and in the Invertebrata, the ganglia are frequently numerous, and are scattered through the system, without much connection with each other,—each having a distinct function. In Vertebrate animals, on the other hand, they are united into one mass,—partly, it would seem, for the sake of the protection afforded them by the bony skeleton,—and partly in order that more complete consentaneousness of action may be attained. Still, several distinct divisions may be traced in the centres of the cerebro-spinal system,—partly by the determination of their respective functions, as indicated by observation and experiment,—and partly by the study of the distribution of the nerves proceeding from them. In this manner we arrive at the knowledge of several distinct ganglionic centres, of which the following may be considered as a general account.

I. The True Spinal Cord, consisting of a nucleus of grey matter, receiving afferent fibres, and giving origin to efferent; by these it is connected with all parts of the body, but especially with the surface and muscles of the extremities. The actions of this centre may be performed without consciousness on the part of the individual; and they consist in the reflection of a motor impulse along an efferent nerve, on the reception of a stimulus conveyed by an afferent or excitor nerve. These reflex movements can be best excited, when the muscles are removed from the control of the will, which otherwise would generally antagonize them. Some of them are connected with the maintenance of the organic functions; and others with the protection or withdrawal of the body from injury. Muscular movements may also be excited by a stimulus directly applied to the Spinal Cord itself (§ 157—212).

* In neither case, however, can the word *terminate* be used with strict correctness; since there is good reason to believe that the apparent termination is not real, but that the ultimate fibres spread from each other in loops, so as to form a plexus, in which there is no loss or cessation of any one of them.

II. The Medulla Oblongata, or cranial prolongation of the Spinal Cord. The actions of this do not essentially differ from those of the true Spinal Cord; but they are connected with different organs. This part consists chiefly of the centres of the nerves of Respiration and Deglutition,—two functions of which the continual maintenance is essential to the life of the being; and it would seem as if these were placed within the cranium, to be more secured from accidental injury. The movements concerned in Respiration and Deglutition are, like those excited through the true Spinal Cord, of a strictly reflex character, being in all instances due to an impression originating in the periphery of the system, which, being conveyed to the centre, excites there a motor impulse; and they, also, are independent of Sensation (§ 184—194).

III. The Ganglia of the nerves of Special Sensation, which form, as it were, the continuation of the Medulla Oblongata. These, also, appear to minister to actions, which do not differ widely from the Reflex in character,—being almost necessarily excited by certain stimuli, and being only in a degree controllable by the will. But their actions differ in this,—that they are attended with consciousness, and also, it would appear, with certain peculiar feelings. Reasons have been given for the belief, that these ganglia are the centres of those actions, which are commonly termed *instinctive* in the lower animals, and *consensual* and *emotional* in ourselves; these all correspond, in being performed without any idea of a purpose, and without any direction of the will,—being frequently in opposition to it (§ 258—265).

IV. The Cerebral Hemispheres or ganglia, which are evidently the instruments or organs of the intellectual faculties. These are connected, by fibres of communication, with almost all parts of the body; and from their proportional size in Man, it seems probable, that many of the nervous trunks are principally composed of such fibres. It is probably by them alone, that ideas or notions of surrounding objects are acquired, and that these ideas are made the groundwork of mental operations. They would seem, also, to be the exclusive seat of Memory. The results of these operations are manifested on the bodily frame, through the Will, which is capable of acting in greater or less degree, on all the muscles forming part of the system of Animal life (§ 279—292).

V. The Cerebellum, which appears to be concerned in the regulation and harmonization of Muscular movement, whetherI nstinctive or Voluntary (§ 266—278).

Tabular View of the Nervous Centres.

	Cerebral Ganglia, the centres of the operations of intelligence and will.	
Nerves of special sensation.—Motor fibres mingled with general motor system.	Ganglia of Special Sense, the centres of consensual, instinctive, and emotional actions.	Nerves of special sensation.—Motor fibres mingled with general motor system.
	Cerebellic Ganglia, for harmonization of general muscular actions.	
Afferent and Motor Nerves of Respiration, Deglutition, &c.	Respiratory and stomato-gastric Ganglia.	Afferent and Motor Nerves of Respiration, Deglutition, &c.

Trunks of Spinal nerves, composed of fibres from true Spinal Cord, and from Cerebrum, Cerebellum and Medulla Oblongata; each group containing afferent and efferent fibres.	Fibrous structure, continuous with Brain. True Spinal Cord, consisting of chain of ganglia, for Reflex actions of the trunk and extremities. Fibrous structure, continuous with Brain.	Trunks of Spinal nerves, composed of fibres from true Spinal Cord, and from Cerebrum, Cerebellum, and Medulla Oblongata; each group containing afferent and efferent fibres.

295. The distinctness of the operations of these several centres is shown in various ways; but especially by conditions of the bodily system, in which one or more of them is in a state of inaction, whether temporary or permanent, or is prevented, by the interruption of the usual channel of communication, from operating on particular parts. Thus, in ordinary profound sleep, which is a state of complete unconsciousness, it is evident that the Cerebral Hemispheres, and the Ganglia of Special sense, are at rest; as the Cerebellum, also, may be considered to be; but the Medulla Oblongata and Spinal Cord must be in complete functional activity. The same is the case in the profound Coma, resulting from effusion of blood, or from narcotic poisons, but not affecting the power of breathing or swallowing. It may be frequently observed, that the sleep is not so profound as entirely to suspend the consciousness of the individual; and that various movements of an *adaptive* character are performed, tending to relieve uneasiness resulting from various causes. In this condition it seems not improbable that the sensory ganglia are in some degree awake, and that the movements are of an instinctive character;—the mind of the individual not being sufficiently active to discern the cause of the uneasiness, or to employ his intelligence in the removal of it. Whenever dreaming takes place, it is evident that the Cerebrum is in a state of partial activity. The state of Dreaming and many forms of Insanity have considerable analogy with each other, especially in the absence of the power, which is so characteristic of the well-regulated mind of Man, of controlling and regulating the current of thought. One idea calls up another according to their previous associations; and the most incongruous combinations are frequently the result: but it will generally, if not always, be found, that the ideas themselves have been previously in the mind, and that no entirely new train of thought is started. Of the degree in which, when the mind is thus closed to the external world, the hidden stores of memory are opened to its search, many very curious instances are recorded.

296. The state of Somnambulism appears to be one degree nearer to that of wakeful activity of the whole mind, than is that of Dreaming. In the latter condition, the individual is unconscious of external objects; for, if they produce an effect upon him, it is in modifying the current of ideas, frequently in some very ludicrous manner: and he does not form any true perception or idea of their nature. But in Somnambulism, his senses are partly awake, so that impressions made upon them may be properly represented to the mind, and excite there the ideas with which they are con-

nected; moreover, the Cerebellum is also awake, so that the movements which the individual performs, are perfectly adapted to their object; indeed it has frequently occurred, that the power of balancing the body has been so remarkably exercised in this condition, that sleep-walkers have traversed narrow and difficult paths, over which they could not have passed in open day, when conscious of their danger. In Somnambulism, as in Dreaming, there is an evident want of voluntary control over the thoughts; their succession is more influenced, however, by impressions received from without, than it is in dreaming; and hence the mind may sometimes be easily guided into a particular train, by properly directing the impressions made upon the sensory organs. It may be remarked, however, that impressions which do not in some degree harmonize with the train of ideas, are not received by the mind; or, at any rate, they are not applied to the correction of the erroneous notions which possess it. But there are many different shades in the condition of the mind, between Dreaming and Somnambulism; the individual being, in some cases, much less conscious of external objects, than he is in others. In some instances it appears as if the mind was so wholly engrossed in a particular train of thought, that it could not be affected by any new sensations; this has its parallel in the waking state. In the Somnambulism induced by the influence of the so-called Animal Magnetism, it is asserted that the individual is so completely unconscious of external impressions, that injuries which would ordinarily produce violent pain are not felt,—so that here the inactivity of the sensory ganglia must be much greater than during ordinary sleep: and yet that the Somnambulist is capable of hearing any questions addressed to him by the Magnetizer, or by a person placed in communication with him by the latter.. That these phenomena really are as thus represented, must be considered as still doubtful; since so many sources of fallacy attend their manifestation, that they can scarcely be yet received as ascertained truth. Complete insensibility to bodily pain is well known, however, to be a not unfrequent condition in ordinary Somnambulism; and the chief questions are—what is the peculiarity of the influence by which Magnetic Somnambulism is induced,—and what are the peculiar phenomena which distinguish this state. On this head there is so much difference of opinion amongst those who have themselves witnessed the phenomena, that those who have not are scarcely justified in coming to decided conclusions either way. A very remarkable characteristic of the state of Somnambulism, is the complete isolation which commonly exists, between the trains of thought which then occupy the mind, and its operations during the waking hours; so that in neither state is there a remembrance of what passes in the other. There is usually this difference, however;—that the mental operations which take place in Somnambulism are, like those of dreaming, frequently suggested by what has previously been occupying the mind; whilst these seem to leave no impression to be retraced in the waking state, though all that passes in one fit of Somnambulism may be recollected in the next. This has been most remarkably observed in the phenomena of that curious state, which is known under the name of double consciousness;* in this, the form of Somnambulism in which there is a consciousness of external impressions, seems to alternate with the condition of ordinary mental activity, and the individual leads (as it were) two distinct lives, recollecting in each con-

* Much interesting information on this and other subjects alluded to in this section, may be found in Dr. Abercrombie's Treatise on the Intellectual Functions.

dition what happened in previous states of the same character, but knowing nothing of the occurrences of the other.*

297. We have thus witnessed several varieties in the condition of the bodily system, depending upon partial or complete suspension of the functional activity of the Cerebrum, Cerebellum, and Sensory ganglia. There is no normal condition of the Spinal system, which at all corresponds with these; since its operations are so closely connected with the maintenance of the organic functions, that the suspension of them necessarily induces the cessation of the latter. This is especially the case, however, in regard to the respiratory ganglion; and the whole remainder of the Spinal Cord may be removed, without the interruption of the movements which are dependent on it. Cases have occurred, however, in which the natural performance even of these has been partially or entirely suspended; and in which the maintenance of life has for a time been effected by a voluntary exertion of the muscles of Respiration. The influence of the will upon the general motor apparatus of Man seems to predominate so greatly over the Reflex action of the Spinal Cord, that few phenomena which are attributable to the latter ordinarily present themselves; these are manifested, however, when the influence of the Brain over any part is cut off, as is seen in certain cases of paralysis. These morbid conditions present us, also, with illustrations of other effects of the interruption of the communication between the nervous centres and particular sets of muscles. Thus, the influence of the Will may be cut off, although that of the Instincts, Emotions, and Reflex Function may remain; or the respondence of the muscles to Emotion may be prevented, whilst they are still capable of Voluntary control, or of Reflex action. Such cases seem to point very clearly to three distinct primary centres of Nervous agency;—and to these, the Cerebrum, Sensory Ganglia, and Spinal Cord (including the Medulla Oblongata) have been here assigned as the instruments. We shall next inquire into some other morbid conditions of the system, which seem due to the irregular action of these; and in this we shall be chiefly guided by the researches of Dr. M. Hall, which have been already slightly glanced at (§ 211, 212).

298. Of the Convulsive diseases, it appears that the greater part, if not the whole, may be attributed to a morbid state of the Spinal System of nerves. Of these, Tetanus is one of the most interesting and instructive forms. This disease is evidently dependent upon a state of undue excitability of the whole spinal system; and this may be produced by different causes. That which is termed the idiopathic form of the disease has its origin in the centres; it may result in Man from the operation of various predisposing and exciting causes; and may be artificially induced in Animals by the administration of Strychnia. In the traumatic form of the disease, the morbid state has its origin in a local injury; and the irritation propagated from this, and operating through the Spinal Cord, may be itself a cause of many of the convulsive movements. But, when the irritable state is once established in the nervous centres, convulsive action of the muscles may be excited by any stimuli, and even almost entirely without external causes. Hence it is that, whilst the amputation of the injured part is not unfrequently the means of saving the patient, if performed sufficiently early, it is attended with no benefit if delayed. The cerebral apparatus is entirely unaffected in this disorder; but the nerves of deglutition are usually

* We never hear of *triple* consciousness. Is it not possible that the curious phenomena here adverted to may depend upon the distinct action of the two Hemispheres of the Cerebrum? See Dr. Holland's very interesting Essay "On the Brain as a Double Organ."

those first influenced by it; those of respiration, however, being soon affected, as also those of the trunk in general. The condition termed Hydrophobia is nearly allied to that of traumatic Tetanus, differing chiefly in the mode in which the cerebro-spinal axis is affected. The irritable state of the nervous centres results from a local injury of a peculiar kind; and here, too, the early removal of the part is very desirable as a means of prevention, although, when the malady has once reached the centres, it is of no use. The muscles of respiration and deglutition are, as in Tetanus, those spasmodically affected in the first instance; but there is this curious difference in the mode in which they are excited to action,—that, whilst in Tetanus the stimulus operates through the true Spinal Cord (either centrally, or by being conveyed from the periphery), in Hydrophobia it is often conducted from the ganglia of special sense, or even from the brain; so that the sight or sound of fluids, or even the idea of them, occasions, equally with their contact, or with that of a current of air, the most distressing convulsions.

299. Epilepsy is another convulsive disease principally involving the Spinal Cord, but partly affecting the Brain. The predisposition to convulsive movements may depend upon many causes; but the movements themselves are in general immediately excited by some local irritation, as by the presence of undigested matter in the stomach, of worms in the intestines, &c., although frequently also from causes purely mental. The convulsive movements usually affect the muscular system very extensively; acting especially upon the muscles of ingestion and egestion. The Brain is evidently much concerned in the disease, however; as is evident from the numerous instances in which it has been clearly traced to some local affection of that organ, as well as from the loss of consciousness which accompanies the convulsion. Many forms of that protean malady, Hysteria, are attended with a similar irritability of the Nervous Centres; but there is this remarkable difference in the two cases,—that the morbid phenomena of Hysteria, whilst they often simulate those of Tetanus, Hydrophobia, Epilepsy, &c., are evidently dependent upon a state of the system of a much less abnormal character, being relieved by very mild remedies, and often being capable of prevention by a strong effort of the will. Dr. Hall has pointed out an important distinction between Epilepsy and Hysteria, which materially influences the proximate danger of the paroxysm of each respectively; in the former, the larynx is convulsively closed, and partial asphyxia is the necessary result, if the access of air be too long prevented, so that venous congestion ensues, increasing the disorder of the nervous centres even to a fatal degree; in Hysteria, on the contrary, much as the larynx is affected, it is never closed.

300. The foregoing are the chief *general* spasmodic diseases in which the Spinal system of nerves is evidently involved;* but there are many others of a more local character. Such are the various forms of Spasmodic

* Chorea is ranked by Dr. M. Hall as a disease of the Spinal System of nerves; but this can scarcely be regarded as a correct determination. It is true that there is considerable irregularity in the ordinary Reflex actions; but the irregularity is still greater in those to which volition or emotion are the stimuli. Moreover, the body is at rest during sleep; and "the Spinal system never sleeps." According to the view here given of the functions of the Cerebellum, it may be questioned whether that organ is not the chief seat of the disease. Stammering may be regarded as a sort of Chorea affecting the muscles of voice; of this more hereafter (CHAP. VI.) In Paralysis Agitans, it may be usually observed, that the voluntary actions are much more affected than the reflex; the latter, indeed, not in general manifesting any disturbance. An interesting and well-marked case of this disease has been mentioned to the Author by Dr. W. Budd, in which softening was found in the Crura Cerebri.

Asthma, the attacks of which generally result from some internal irritation, either in the lungs themselves or in the digestive system, producing a reflex action upon the muscular fibres of the bronchial tubes. The Croup-like Convulsion, or Crowing Inspiration of Infants, again, is an obstruction to the passage of the air through the glottis, by a spasmodic contraction of the constrictors of the larynx. This spasmodic action may be induced by various kinds of irritation; such as that occasioned by teething, by the presence of undigested food, or by intestinal disorder. In the crowing inspiration, the larynx is partially closed; when the spasm is severe, however, there is complete occlusion of the passage, and forcible efforts at expiration are made, which induce, as in epilepsy, a severe degree of venous congestion, and this reacts upon the nervous centres, aggravating the previous disorder of their condition. The present increased knowledge of the functions of the laryngeal nerves, and of the symptoms of this disease, appears to render inadmissible the explanation of it given not long since by Dr. H. Ley, who attributed it to paralysis of the pneumogastric nerves occasioned by pressure.—Spasmodic closure of the larynx may occur from other causes. When the rima-glottidis is narrowed, by effusion of fluid into the substance of its walls, it is very liable to be completely closed by spasmodic action, to which the unduly irritable condition of the mucous membrane will furnish many sources of excitement. Choking, again, does not result so much from the pressure of the food on the air-passages themselves, as from the spasmodic action of the larynx excited by this; and the dislodgement of the morsel by an act of vomiting is the most effectual means of obtaining relief.—Tenesmus and Strangury are well-known forms of spasmodic muscular contraction, excited by local irritation acting through the Spinal system. The abnormal action which leads to Abortion is frequently excited in the same manner; how far the uterus itself is called into contraction by the ordinary spinal nerves, is a question as yet undecided; but the facts already stated leave no doubt, that stimuli operating on these may act upon it through the Sympathetic into which their fibres pass (§ 203). It will be borne in mind, however, that, in abortion, as in ordinary parturition, many muscles are called in, to aid the contractions of the uterus, which are strictly under the dominion of the Spinal system.—There is a form of Incontinence of urine, which is very analogous to the morbid action just described; the sphincter has its due power; but the stimulus to the evacuation of the bladder is excessive in strength and degree, owing to the acridity of the urine or other causes. The part of the bladder upon which this appears chiefly to act, is the trigonum, which is well known to be more sensitive to the irritation of calculi, than the rest of the internal surface; and Sir C. Bell advises young persons who suffer during the night from this very disagreeable complaint, to lie upon the belly instead of the back, so that the contact of the urine with the trigonum may be delayed as long as possible.

301. One of the most familiar examples of the pathological excitement of the true Spinal system, is the act of Vomiting; and, as Dr. M. Hall justly remarks, the special function of this system nowhere receives better illustration. The act may be excited in various ways. Thus, it results from the tickling of the fauces with a feather or with the finger; but if the feather be carried too far down, an act of deglutition is induced, instead of vomiting.* In this instance the glosso-pharyngeal, and perhaps also the fifth

* This has been the cause of many accidents. Patients have tickled the fauces with a feather, in order to excite vomiting; and, having introduced it too far into the pharynx, it has been drawn out of their fingers, by the muscles of deglutition, and

pair, are the nerves by which the stimulus is conveyed to the Medulla Oblongata. Vomiting, again, may be induced by substances introduced into the stomach; and here the pneumogastric is evidently the excitor. When it takes place as a result of pregnancy, or of some intestinal irritation, the stimulus must be conveyed either through one of the ordinary Spinal nerves, or through the Sympathetic. But it may also be occasioned by the sight, smell, or taste of any disagreeable object, or by the mere conception of it, or by mental emotion simply. In this case, the stimulus appears to be received by the ganglia of special sense, and to be transmitted by them to the muscles concerned, as by the Spinal Cord or Medulla Oblongata in the former case. When Vomiting is excited by the introduction of emetic substances into the blood (§ 199), it is probable that their stimulation chiefly operates through the extended plexus of nerves spread out by the Sympathetic upon the walls of the blood-vessels; but the irritant action of the substance upon the nervous centres may be also concerned. In regard to the mechanism by which the act of Vomiting is produced, considerable difference of opinion has existed. The old opinion was, that it was occasioned by the simple contraction of the stomach itself; but Magendie proved that this could not be the case, by substituting a bladder for the stomach of an animal, and then injecting a solution of tartarized antimony into its blood, which immediately caused the emptying of the bladder, by the pressure of the surrounding muscles; these muscles he considered to be the diaphragm and abdominal muscles, the conjoint action of which would be a peculiarity observed in no other instance. By Dr. M. Hall, on the other hand, it is maintained that the act of vomiting is, like the expulsion of the fœtus, urine, fæces, &c., an expiratory effort, modified in its effects by the peculiar condition of the spinchters. It bears, indeed, great resemblance to the act of coughing; differing chiefly in this, that in Vomiting the larynx is closed during the whole operation, whilst it is only closed momentarily in coughing; and also, that in coughing the cardiac orifice of the stomach is closed, whilst in vomiting it is opened. In this view, the accuracy of which has been proved by experiment, the diaphragm is quite inert. A curious case has been recorded by Drs. Graves and Stokes,* in which vomiting took place from the stomach of a man, who was found after death to be the subject of a very remarkable change in the relative position of the viscera,—the stomach lying in the thorax, which cavity communicated with the abdomen by an opening in the diaphragm, giving passage to the œsophagus and duodenum. This case was regarded by its reporters as proving, that vomiting might take place by the action of the stomach alone; but it can scarcely be held to justify this conclusion; since, the diaphragm being entirely passive, the abdominal muscles would have the same power of emptying the stomach as they would possess over the lungs. The conformity of the act of vomiting with that of expiration, is further shown by the ejection of the contents of the œsophagus, which will take place, when it is distended by the deglutition of food that cannot pass on into the stomach, on account of an obstruction at the cardia.

carried into the œsophagus. Similar accidents have occurred with the rectum-bougie, and female catheter, as well as with probes, &c., introduced into the male urethra; all the orifices being furnished with a kind of ingestive power, which is clearly the result of Reflex action.

* Dublin Hospital Reports, Vol. v.

CHAPTER IV.

OF SENSATION, AND THE ORGANS OF THE SENSES.

Of Sensation in General.

302. By the term *Sensation* is rightly understood that change in the condition of the mind, by which we become aware of an impression made upon some part of the body; or, in a briefer form of expression, it may be defined to be the *consciousness of an impression.* Some physiologists have, it is true, spoken of a *sensation without consciousness;* but it seems very desirable thus to limit the term; since the word *impression* may be very well applied to whatever change is produced in the afferent nerves by an external cause, up to the point at which the mind becomes conscious of it. We have seen reason to believe that the impressions communicated to the Spinal Cord may there excite motor actions, without occasioning true Sensation; and it would seem to be with the Brain only, that the Mind possesses the relation necessary for the production in it of such a change. Hence the Brain is spoken of as the Sensorium. For the reasons already given (§ 261), it seems probable that the ganglia of Special Sensation share in this function with the Cerebral Hemispheres. The afferent nervous fibres which connect the various parts of the body with the brain, are termed *sensory.* This term has also been applied to those which terminate in the Spinal Cord; but as the impressions which these convey do *not* produce sensations, it seems desirable to avoid thus designating them; and the term *excitor*, proposed by Dr. M. Hall, is much preferable. Every afferent spinal nerve, therefore, is made up of sensory and of excitor fibres; and these may be distributed in very different proportions to different parts. Of the excitor fibres, enough has been already said. Those parts of the body which are endowed with sensory fibres, and impressions on which, therefore, give rise to sensation, are ordinarily spoken of as *sensible;* and different parts are spoken of as sensible in different degrees, according to the strength of the sensation which is produced by a corresponding impression on each.

303. In accordance with what was formerly stated (§ 118) of the dependence of all nervous action on the continuance of the capillary circulation, especially at the extremities of the fibres, it is found that the sensory nerves are distributed pretty much in the same proportion as the blood-vessels: that is to say, in the non-vascular tissues,—such as the epidermis, hair, nails, and bony substance of the teeth, no nerves exist, and there is an entire absence of sensibility; and in those whose vascularity is trifling, the sensibility is dull, as is the case with bones, cartilages, tendons, ligaments, fibrous membranes, and other parts whose functions are simply mechanical, and even with serous and cellular membranes. Many of these textures are acutely sensible, however, under certain circumstances; thus, although tendons and ligaments may be wounded, burned, &c., with little or no consciousness of the injury, they cannot be stretched without considerable pain; and the fibrous, serous, and cellular membranes, when their vascularity is increased by inflammation, also become extremely susceptible of painful impressions. All very vascular parts, however, do not possess acute sensibility; the muscles, for instance, are furnished with a large supply of blood,

to enable them to perform their peculiar function, but they are not sensible in by any means the same proportion. Even the substance of the brain and of the nerves of special sensation appears to be destitute of this property; and the same may be said of the mucous membranes lining the interior of the several viscera, which, in the ordinary condition, are much less sensible than the membranes which cover those viscera, although so plentifully supplied with blood for their especial purposes. The most sensible of all parts of the body is the skin, in which the sensory nerves spread themselves out into a minute network; and even of this tissue the sensibility differs greatly in different parts. The organs of special sensation are, by the peculiar character of the nerves with which they are supplied, rendered sensible to impressions of a particular kind; thus, the eye is sensible to light, the ear to sound, &c.; and whatever amount of ordinary sensibility they possess is dependent upon other sensory nerves. The eye, for example, contrary to the usual notions, is a very insensible part of the body, unless affected with inflammation; for though the mucous membrane which covers its surface, and which is prolonged from the skin, is acutely sensible to some kinds of impressions, the interior is by no means so, as is well known to those who have operated much on the eye. And there are many parts of the body, that are supplied with the common sensory nerves, which convey to the mind impressions of some kinds with much greater readiness than they communicate those of a different description.

304. It appears, then, that the vascularity of a part is an essential condition of its sensibility; but it does not follow that a tissue should be peculiarly sensible because it is highly vascular, since its large supply of blood may be required for other purposes. It is not simple vascularity, however, which is necessary, but rather an active capillary circulation; any cause which retards this, deadens the sensibility, as is well seen in regard to cold; and, on the other hand, an increase in its energy produces a corresponding increase in the sensibility, as is peculiarly evident in the active congestion which usually precedes inflammation. Acute sensibility to external impressions may arise, however, not only from abnormal activity of the circulation in the organ or part itself, but from the same condition affecting that part of the sensorium in which the impressions are received. Thus in active congestion and inflammation of the brain, the most ordinary external impressions produce sensations of an unbearable violence; and there are some peculiar conditions of the nervous system, known under the name of hysterical, in which the patients manifest the same discomfort, even when the circulation is feeble, rather than in an excited state. It is remarkable that the sensibility of the mucous membranes lining the internal organs is less exalted by the state of inflammation, than is that of most other parts; and in this arrangement we may trace a wise and beneficient provision; since, were it otherwise, the functions necessary to life could not be performed without extreme distress, with a very moderate amount of disorder in the viscera. If a joint is inflamed, we can give it rest; but to the actions of the alimentary canal we can give little voluntary respite.

305. The feelings of Pain or Pleasure which are connected with particular sensations, cannot (for the most part at least) be explained upon any other principle, than that of the necessary association of these feelings, by an original law of our nature, with the sensations in question. As a general rule it may be stated, that the *violent* excitement of *any* sensation is disagreeable, even when the same sensation in a moderate degree may be a source of extreme pleasure. This is the case alike with those impressions which are communicated through the organs of sight, hearing, smell, and

taste, as with those that are received through the nerves of common sensation; and there can be no doubt that the final cause of the association of painful feelings with such violent excitement, is to stimulate the individual to remove himself from what would be injurious in its effects upon the system. Thus, the pain resulting from violent pressure on the cutaneous surface, or from the proximity of a heated body, gives warning of the danger of injury, and excites mental operations destined to remove the part from the influence of the injurious cause; and this is shown by the fact, that loss of sensibility is frequently the indirect occasion of severe lesions,—the individual not receiving the customary intimation that an injurious process is taking place. Instances have occurred, in which severe inflammation of the membrane lining the air-passages has resulted from the effects of ammoniacal vapours introduced into them during a state of syncope,—the patient not receiving that notice of the irritation, which would, in an active condition of his nervous system, have prevented him from inhaling the noxious agent. It is a general rule, with regard to all sensations, however, that their intensity is much affected by habit; being greatly diminished by frequent and continual repetition. This is partly due to the different degree of attention which the sensations excite in the mind; but there are many facts which lead to the conclusion, that it is chiefly to be attributed to a change in the degree in which, after frequent repetition, they impress the consciousness itself. Thus, most persons are readily awoke from a sound sleep by a trifling noise, if the sound be of a kind which they are unaccustomed to hear; but after a few repetitions, the sound loses its effect, unless its intensity be increased. Of this, every one has had experience, who has occasionally made use of an alarum to arouse him for a few mornings in succession. It is curious, also, that the feelings of pain or pleasure which unaccustomed sensations excite, are often exchanged for each other, when the system is habituated to them; this is especially the case in regard to impressions communicated through the organs of smell and taste. There are many articles in common use among mankind,—such as Tobacco, Fermented liquors, &c.,—the use of which cannot be said to produce a natural enjoyment, since it is at first unpleasant to most persons; and yet it first becomes tolerable, then agreeable; and at last the want of them is felt as a painful privation, and the stimulus must be applied in an increasing degree, in order to produce the usual effect.

306. The general law, that sensations are blunted by frequent repetition, may perhaps be connected with certain other general facts, which lie under the observation of every one. It is well known that the vividness of sensations depends rather on the degree of change which they produce in the system, than on the absolute amount of the impressing cause; and this is alike the case with regard to the special and ordinary sensations. Thus, our sensations of heat and cold are entirely governed by the previous condition of the parts affected; as is shown by the well-known experiment of putting one hand in hot water, the other in cold, and then transferring both to tepid water, which will seem cool to one hand, and warm to the other. Every one knows, too, how much more we are affected by a warm day at the commencement of summer, than by an equally hot day later in the season. The same is the case in regard to light and sound, smell and taste. A person going out of a totally dark room into one moderately bright, is for the time painfully impressed by the light, but soon becomes habituated to it; whilst another, who enters it from a room brilliantly illuminated, will consider it dark and gloomy. Those who are constantly exposed to very loud noises, become almost unconscious of them, and are even undisturbed

by them in illness;* and the medical student well knows that even the effluvia of the dissecting-room are not perceived, when the organ of smell is habituated to them; although an intermission of sufficient length would, in either instance, occasion a renewal of the first unpleasant feelings, when the individual is again subjected to the impression.

307. Again, it is a well-known fact, that impressions made upon the organs of sense continue for a time, after the cause of the impression has ceased. It is in this manner that a musical tone, which seems perfectly continuous, results from a series of consecutive vibrations, following each other with a certain rapidity; and that a line or circle of light is produced by a luminous body moving with a certain velocity. Now there is reason to believe that changes, of which the effects thus transiently remain upon the nerves of sense, are more permanently impressed upon the sensorium; since, as formerly shown (§ 291), we can only in this manner account for the phenomena of Memory, and for the effects produced upon this power, by material changes in the brain. Hence the diminution in the force of sensations, which is the consequence of their habitual recurrence, may be considered as resulting from these two general facts,—the persistence of the impression made by them upon the sensorium,—and the consequent absence of a change in *its* state, when a sensory impression is brought to it, which is of the same nature with one already registered there: the degree in which the consciousness is excited, being dependent, as just stated, not upon the absolute degree of the impressing cause, but upon the amount of change which it produces in the sensorial apparatus. In this respect there is a perfect conformity between the law of sensation and that of muscular contraction; for stimuli which excite the latter usually lose their force in proportion to the frequency of their repetition. Indeed both may be considered as results of the more general laws of vitality; for the actions of other tissues follow the same rule, as is shown by the *tolerance*, that may be gradually established in the system, of medicinal agents, poisons, &c., which would have at first produced the most violent effects when given in the same amount.

308. It is through the medium of Sensation, that we acquire a knowledge of the material world around us; and that its changes excite mental operations in ourselves. The various kinds or modes of Sensation excite in us various ideas regarding the properties of matter; and these properties are known to us, only through the changes which they produce in the several organs. Thus a man totally blind from birth can form no idea of the nature of light or colours; nor could one completely deaf have any conception of musical tones. It is well known that instances exist, in which, from some imperfection of the organization, there is an incapacity for distinguishing colours or musical tones, whilst there is no want of sensibility to light or sound; and that some persons are naturally endowed with a much greater range of the sensory faculties than others possess. Hence it does not seem at all improbable, that there are properties of matter, of which none of *our* senses can take immediate cognisance; and which beings might be formed to perceive, in the same manner as *we* are sensible to light, sound, &c. Thus, it is well known that many animals are affected by atmospheric changes in such a manner, that their actions are regarded by man as indications of the probable state of the weather; and the same is the case in a

* This fact is very well known in the manufacturing districts; where it is not at all uncommon for a family to live in the immediate vicinity of a forge-hammer; and those who are accustomed to the noise are unable to sleep anywhere else.

less degree with some of our own species, who are peculiarly susceptible of the same influences. Now the most universal of all the qualities or properties of matter,—that, in fact, on which our notion of it is founded,—is *resistance;* and it is this quality, of which the knowledge seems most universally diffused throughout the Animal kingdom. In the lowest tribes, we find that *contact* between their surface and some material body is required to produce sensation; and beings which cannot be made conscious, in this manner, of the existence of something external to themselves, do not deserve to be ranked in the Animal kingdom. Our difficulty lies (as heretofore remarked, § 113) in ascertaining what are to be regarded, in such beings, as unequivocal indications of consciousness. Those animals which are fixed to one spot can have few other ideas of matter than this most general one; but in those which have the power of locomotion, the general sensibility of the surface doubtless communicates to them some notion of the character of the body over which they move, in the same manner as we learn it by passing the hand over its exterior. We shall presently see, however, that the idea of the *shape* of a body which we form from the touch, results from a very complex process, which animals of the lowest grade can scarcely be supposed to exercise. There can be no doubt that, next to the mere sense of resistance, sensibility to *temperature* is the most universally diffused through the Animal kingdom; and probably the consciousness of *luminosity* is the next in the extent of its diffusion. There is good reason to believe, from observation of their habits, that many animals are susceptible of the influence, and are directed by the guidance of light, whose organs are not adapted to receive true visual impressions, or to form optical images; and such would seem to be the function of the red spots frequently seen on prominent parts of Animalcules, the lower Articulata and Mollusca, and even of some Radiata. Wherever these are of sufficient size to allow their structure to be examined, they are found to be largely supplied with nerves, but to be destitute of the peculiar organization which alone constitutes a true *eye.* The sense of Taste may be considered as a refined modification of that of touch; and it is probable that this exists very low down in the animal scale, being obviously of great importance in the selection of food; but the Anatomist has no means of ascertaining where this refinement exists, and where it does not, since the organs of taste and touch are so similar. The sense of Hearing does not seem to be distinctly present among the Invertebrate animals, except in such as approach most nearly to the Vertebrata; it is not improbable, however, that sonorous vibrations may produce an effect upon the system of those animals which do not receive them as *sound;* and this would appear, from a fact subsequently to be mentioned (§ 320), to be not improbably the case with regard especially to aquatic animals. The sense of Smell, which is concerned with one of the least general properties of matter, appears to be the least widely diffused among the whole; being only possessed in any high degree by Vertebrated animals, and being but feebly present in a large proportion of these.

309. Besides the various kinds of sensibility which have been just enumerated, there are others which are ordinarily associated together, along with the sense of material resistance (and its several modifications), and the sense of temperature, under the head of Common Sensation; but several of them, especially those which originate in the body itself, can scarcely be regarded in this light. Such are the feelings of Hunger and Thirst; that of Nausea; that of distress resulting from suspended aeration of the blood; that of "sinking at the stomach," as it is vulgarly but expressively described,

which results from strong mental emotion; that of the venereal excitement, and perhaps some others. Now in regard to all these, it is impossible in the present state of our knowledge to say, whether their peculiarity results from the particular constitution of the nerves that receive and convey them, or only from a modification in the impressing causes, and in the mode in which they operate. Thus we have no evidence that the nervous fibrils, which convey from the lungs the sense of distress resulting from deficient aeration, may not be of a different character from those which convey from the surface of the air-passages the sense of the contact of a foreign body. But as we know that all the trunks, along which these peculiar impressions travel, do minister to ordinary sensation, whilst the nerves of truly special sensation are not sensible to common impressions, it is evident that the probability is in favour of the correspondence between the fibres which minister to these sensations, and those of the usual sensory character. Even for the sense of temperature, however, it is not by any means certain that a special set of fibres does not exist; for many cases are on record in which it has been lost, whilst the ordinary sense of tact remained; and it is sometimes preserved, when the anæsthesia is in other respects complete.

310. With regard to all kinds of sensation it is to be remembered, that the change of which the mind is informed is *not* the change at the peripheral extremities of the nerves, but the change communicated to the sensorium; hence it results that external agencies can give rise to no kind of sensation, which cannot also be produced by internal causes, exciting changes in the condition of the nerves in their course. This very frequently happens in regard to the senses of sight and hearing; flashes of light being seen, and ringing sounds in the ears being heard, when no external stimulus has produced such impressions. The production of odorous and gustative sensations from internal causes, is perhaps less common; but the sense of nausea is more frequently excited in this manner, than by the direct contact of the nauseating substance with the tongue or fauces. The various phases of common sensibility often originate thus; and it is an additional evidence in favour of the distinctness of the fibres which convey the impressions of temperature, that these are frequently affected,—a person being sensible of heat or of chilliness in some part of his body, without any real alteration of its temperature,—whilst there is no corresponding affection of the tactual sensations. The most common of the internal causes of these *subjective* sensations (as they have been termed, in contradistinction to the *objective* which result from a real material object,) is congestion or inflammation; and it is interesting to remark that this cause, operating through each nerve, produces in the sensorium the changes to which that nerve is usually subservient. Thus, congestion in the nerves of common sensation gives rise to feelings of pain or uneasiness; but when occurring in the retina and optic nerve it produces flashes of light; and in the auditory nerve it occasions a "noise in the ears." It may be observed, also, of some external causes, that they may excite changes in the sensorium through several different channels; and that in each case the sensation is characteristic of the particular nerve on which the impression is made. Thus pressure, which produces through the nerves of common sensation the feeling of resistance, is well known to occasion, when exerted on the eye, the sensation of light and colours; and, when made with some violence on the ear, to produce tinnitus aurium. It is not so easy to excite sensations of taste and smell, by mechanical irritation; and yet, as Dr. Baly* has shown, it may readily

* Translation of Müller's Physiology, p. 1062, *note*.

be accomplished in regard to the former. The sense of nausea may be easily produced, as is familiarly known, by mechanical irritation of the fauces. The stimulus of electricity still more completely possesses the power of affecting all the sensory nerves with the changes which are peculiar to them; for, by proper management, an individual may be made conscious at the same time of flashes of light, of distinct sounds, of a phosphoric odour, of a peculiar taste, and of pricking sensations, all excited by the same cause, the effects of which are modified according to the respective peculiarities of the instruments through which it operates. But although there are some stimuli which can produce sensory impressions on all the nerves of sensation, it will be found that those to which any one organ is peculiarly fitted to respond, produce little or no effect upon the rest. Thus the ear cannot distinguish the slightest difference between a luminous and a dark object. A tuning-fork, which, when laid upon the ear whilst vibrating, produces a distinct musical tone, excites no other sensation when placed upon the eye than a slight jarring feeling. The most delicate touch cannot distinguish a substance which is sweet to the taste, from one which is bitter; nor can the taste (if the communication between the mouth and the nose be cut off) perceive any thing peculiar in the most strongly-odoriferous bodies.

311. It may hence be inferred that no nerve of special sensation can by any possibility take on the function of another. How far the nerves of common sensation can, under any circumstances, perform the offices usually delegated to those of special sense, we are not yet in a condition to determine. Comparative Anatomy seems to show that, in the lowest animals in which the rudiments of eyes can be detected, there is no distinction between the nerves proceeding to these organs, and the rest, and there would appear some ground for the belief that, as in other cases, the special organs of sensibility are gradually elaborated, in ascending the Animal scale, from the more general apparatus, and are not merely superadded to it. Hence we may conceive the possibility (though there is no proof of the fact) that states of the system might occur, in which a change in the common sensory nerves might produce the sensation of light, sound, &c. But it is quite impossible (so far at least as our present knowledge of physical phenomena permits us to decide upon the impossibility of any thing) that distinct visual impressions should be communicated to a nerve, except through the mediation of such an optical instrument as the eye; or distinct sonorous impressions, except through such an acoustic instrument as the ear. Hence we must receive with utter discredit the wonderful accounts of transference of sensation, with which the credulous public have been deceived, at various times. Still it may be objected that, as we are so totally destitute of real knowledge, as to the mode in which vision is ordinarily produced by inverted images upon the retina, we have no right to assert that it may not take place in some other way; and perhaps this objection should lead us to consider the phenomenon rather as *extremely improbable*, than as *impossible*. But the improbability may be compared to that of a stone ascending like a balloon, or a piece of lead floating on the water; for we have no more knowledge of the ultimate cause of that which we term the force of Gravitation, than we have of the nature of Sensation.

312. The peculiar aptitudes of the different sensory nerves to receive and convey impressions of various kinds, must be regarded as the result of properties inherent in themselves; just as we consider the difference between the afferent nerves in general, and the motor nerves, to be one belonging to their own constitution. But it is probable that there are also

different localities in the sensorium, in which the changes to which they give rise are performed. This may be judged of from the fact, that the phenomena of subjective sensation frequently originate in peculiar conditions of the encephalon itself, and not in the nervous trunks or organs of sense; thus, in dreaming, we have frequently very vivid pictures of external objects presented to our minds; and we sometimes distinctly hear voices and musical tones, or have perceptions (though this is less common) of tastes and odours. The phenomena of spectral illusions are very nearly connected with those of dreaming; both may be in some degree influenced by external causes acting upon the organs of sensation, which are misinterpreted (as it were) by the mind, owing to its state of imperfect operation; but both also may entirely originate in the central organs. There seems to be no difference, in the feelings of the individual, between the sensations thus originating, and those which are produced in the usual manner; for we find that, unless otherwise convinced by their own reason, persons who witness spectral illusions believe as firmly in the reality of the objects that come before their minds, as if the images of those objects were actually formed on their retinæ. This is another proof, if any were wanting, that the organ of sense, and the nerve belonging to it, are but the instruments by which certain changes are produced in the sensorium; of which changes, and not of the immediate impression of the object, the sensation really consists. It seems to be by an innate law of our constitution, that these subjective sensations, whether originating in the central organs, or in the course of the nervous trunks, should be referred by the mind to the ordinary situations of the peripheral terminations of those nerves; even though these should not exist, or should be destitute of the power of receiving impressions. Thus after amputations, the patients are for some time affected with sensations (originating probably in the cut extremities of the nerves), which they refer to the removed extremities; the same has been noticed in regard to the eye, as well when it has been completely extirpated, as when its powers have been destroyed by disease. The effects of the Taliacotian operation also exhibit the operation of this law in a curious manner; for, until the flap of skin from which the nose is formed obtains vascular and nervous connections in its new situation, the sensation produced by touching it is referred to the forehead. Another interesting illustration of it may be obtained by the following very simple experiment:—if the middle finger of either hand be crossed behind the fore-finger, so that its extremity is on the radial side of the latter, and the ends of the two fingers thus disposed be rolled over a marble, pea, or other round body, a sensation will be produced, which, if uncorrected by reason, would cause the mind to believe in the existence of two distinct bodies; this is due to the impression being made at the same time upon the radial side of the fore-finger, and the ulnar side of the middle finger,—two joints which, in the natural position, are at a considerable distance.

313. The acuteness of particular sensations is influenced in a remarkable degree by the attention they receive from the mind. If the mind be entirely inactive, as in profound sleep, no sensation whatever is produced by ordinary impressions; on the other hand, when the mind is from any cause strongly directed upon them, impressions very feeble in themselves produce sensations of even painful acuteness. Every one knows how much a slight itching of some part of the surface may be magnified by the direction of the thoughts to it; whilst as soon as they are forced by some stronger impression into another channel, the irritation is no longer felt. To the traveller in warm countries, the shrill but feeble buzz of a single mosquito,

accidentally enclosed within the netting that surrounds his bed, becomes a source of almost inexpressible annoyance when he is composing himself to sleep; and every one is aware how vividly other sounds are perceived, when they break in upon the stillness of the night,—being increased in strength, not only by the contrast, but by absorbing the whole attention. An interesting experiment is mentioned by Müller, which shows how completely the mind may be unconscious of impressions communicated to it by one organ of sense, when occupied, even without a distinct effort of the will, by those received through another. If we look at a sheet of white paper through two differently coloured glasses at the same time,—one being placed before each eye, the resulting sensation is seldom that of a mixture of the colours; if the experiment be tried with blue and yellow glasses, for example, we do not see the paper of an uniform green, but the blue is predominant at one moment, and the yellow at another, or blue nebulous spots may present themselves on a yellow field, or yellow spots on a blue field. We perceive from this experiment, that the attention may not only be directed to the impressions made on either retina, to the complete exclusion of those of the other, but it may be directed to those made on particular spots of either. This may be noticed, again, in the process by which we make ourselves acquainted with a landscape or a picture; if our attention be directed to the whole field of vision at once, we see nothing distinctly; and it is only by abstracting ourselves from the contemplation of the greater part of it, and directing our attention to smaller portions in succession, that we can obtain a definite conception of the details. The same is the case in regard to auditory impressions; and here the power of attention in causing one sensation or series of sensations to predominate over others which are really more intense, is often most remarkably manifested. When we are listening to a piece of music played by a large orchestra, for example, we may either attend to the combined effect of all the instruments, or we may single out any one part in the harmony, and follow this through all its mazes; and a person with a practised ear (as it is commonly but erroneously termed, it being not the ear but the mind that is practised,) can even distinguish the sound of the weakest instrument in the whole band, and can follow its strain through the whole performance. This attention to a single element can only be given, however, by withdrawing the mind from the perception of the rest; and a musician who thus listens, will have very little idea of the rest of the harmonic parts, or of the general effect. In fact, when the mind is thus directed, by a strong effort of the will, into a particular channel, it may be almost considered as unconscious *quoad* any other impressions.

314. The effects of this principle are manifested in regard to the sensations which originate within the system, as well as in respect to those which are excited by external impressions. Every one is aware how difficult it is to keep the body perfectly quiescent,* especially, when there is a particular motive for doing so, and when the attention is strongly directed to the object. This is experienced even whilst a Photogenic likeness is being taken, when the position is chosen by the individual, and a support is adapted to assist him in retaining it; and it is still more strongly felt by the performers in the Tableaux Vivans, who cannot keep up the effort for more than three or four minutes. Now it is well known that, when the attention is strongly directed to an entirely different object (when we are listening, for example, to an eloquent sermon, or an interesting lecture), the body may

* Of course the movements of respiration and winking are left out of the question.

remain perfectly motionless for a much longer period; the uneasy sensations which would otherwise have occasioned the individual to change his position, not being felt: but no sooner is the discourse ended, than a simultaneous movement of the whole audience takes place, every one becoming then conscious of some discomfort, which he seeks to relieve. This is the case also in regard to the respiratory sensation; in general it may be observed, that the usual reflex movements are not enough for the perfect aeration of the blood, and that a more prolonged inspiration, prompted by an uneasy feeling, takes place at intervals; but under such circumstances as those just alluded to, this feeling is not experienced until the attention ceases to be engaged by a more powerful stimulus, and then it manifests itself by the deep inspirations which accompany, in almost every individual, the general movement of the body.

315. It is curious that the constant direction of the attention to internal sensations of a *subjective* kind, should sometimes occasion actual disorder of the parts to which these sensations are referred; and yet this seems the only way of accounting for some of the phenomena of disease. Sometimes the cause of the sensation may exist in the trunk of the nerve in some part of its course; whilst in other instances it may be confined to the sensorium. Pain of the testicle, for example, may be occasioned by irritation having its seat in the lower part of the spine, the organ itself being perfectly sound; yet if that pain continue, it may become diseased. The following are some very interesting remarks on this subject, from the able pen of Dr. Holland.* "There is cause to believe the action of the heart to be quickened or otherwise disturbed, by the mere centering of consciousness upon it, without any emotion or anxiety." This is especially the case where the pulsations are irregular, or are so loud as to be audible. "The same may be said of the parts concerned in respiration. If this act be expressly made the subject of consciousness, it will be felt to undergo some change; generally to be retarded at first, and afterwards quickened." "The act of swallowing is manifestly rendered more difficult by the attention being fixed upon it; and the same cause will often be found to render articulation less distinct, especially when there exists already some impediment to the function. A similar direction of consciousness to the region of the stomach creates in this part a sense of weight, oppression, or other less definite uneasiness; and, when the stomach is full, appears greatly to disturb the due digestion of the food. The state and action of the bowels are much influenced by the same cause." A peculiar sense of weight and restlessness, approaching to cramp, is felt in a limb, to which the attention is particularly directed. "The attention concentrated, for so by an effort of will it may be, on the head or sensorium, gives certain feelings of tension and uneasiness, caused possibly by some change in the circulation of the part; though it may be an effect, however difficult to be conceived, on the nervous system itself. Persistence in this effort, which is seldom indeed possible beyond a short time without confusion, produces results of much more complex nature, and scarcely to be defined by any common terms of language." These phenomena have an evident affinity with those of several morbid conditions. Thus the hypochondriac patient "in fixing his consciousness with morbid intentness on certain organs, creates not merely disordered sensations, but often also disordered actions in them. There may be palpitation of the heart, hurried or choked respiration, flatulence and other distress of stomach, irritation of the bladder; all arising from this morbid direction of attention to the organs

* Medical Notes and Reflections, Chap. v.

in question." In hysteria, again, "the instances are frequent of attacks brought on by the mere expectation of them; or by imitation; or occasionally even by a sort of morbid solicitation of the organs to these singular actions." These facts go a long way to explain the phenomena of Animal Magnetism, many of which are obviously to be referred to the exaggerated operation of the same principle.

We now proceed to consider in more detail the functions of the several Organs of the Senses, and shall commence with that of the most general character.

Sense of Touch.

316. By the sense of Touch, as commonly understood, is meant that modification of the common sensibility of the body, of which the cutaneous surface is the especial seat. It derives its peculiar powers simply from the large amount of sensory nervous fibres, which are distributed in its substance; and especially through the terminations (or rather the origins) of these in the *papillæ*, which are little elevations of the surface of the cutis, easily perceptible by the aid of a lens, and each chiefly composed of a vascular plexus surrounding the extremity of the nervous fibril. The number of these papillæ within any given area, pretty closely corresponds with the degree of sensibility of that part of the surface; thus we find them most abundant on the hands, especially towards the points of the fingers, and on the lips and tongue. In some animals, especially those of the Feline tribe, the long *vibrissæ* (commonly termed whiskers) evidently minister to sensation; and it has been demonstrated that their pulps are largely supplied with nerves from the fifth pair. Some interesting observations have been made by Prof. Weber on the sensibility of different parts of the skin. His mode of ascertaining this was to touch the surface with the legs of a pair of compasses, the points of which were provided with pieces of cork; the eyes being closed at the time, the legs were approximated to each other, until they were brought within the smallest distance at which they could be felt to be distinct from one another. The following are some of the results of the experiments. With the extremities of the fingers and the point of the tongue, the distance could be distinguished most easily in the longitudinal direction; on the dorsum of the tongue, the face, neck, and extremities, the distance could be recognised best when the arms were placed transversely.

Point of middle finger -	$\frac{1}{3}$ of a line	Mucous membrane of gums	9 lines
Point of tongue - -	$\frac{1}{2}$ of a line	Lower part of forehead	10 —
Palmar surface of third finger	1 line	Lower part of occiput -	12 —
Red surface of lips - -	2 lines	Back of hand - - -	14 —
Palmar surface of middle finger	2 —	Neck, under lower jaw -	15 —
Dorsal surface of third finger	3 —	Vertex - - - - -	15 —
Tip of the nose - - -	3 —	Skin over Patella - -	16 —
Dorsum and edge of tongue	4 —	——— Sacrum - -	18 —
Part of lips covered by skin	4 —	——— acromion -	18 —
Palm of hand - - -	5 —	Dorsum of foot - -	18 —
Skin of cheek - - -	5 —	Skin over sternum - -	20 —
Extremity of great toe -	5 —	Skin beneath occiput -	24 —
Hard palate - - -	6 —	Skin over spine, in back -	30 —
Dorsal surface of forefinger	7 —	Middle of the arm - -	30 —
Dorsum of hand - - -	8 —	——— thigh -	30 —

It is curious that the distance between the legs of the compasses seemed to be greater (although really so much less), when it was felt by the more sensitive parts, than when it was estimated by parts of less distinct sensi-

bility. As a general fact, it seems that the sensibility of the trunk is greater on the median line, both before and behind, and less at the sides. Differences of temperature, and the weight of bodies, were, according to Prof. Weber's observations, most accurately recognised at the parts which were determined to be most sensible by the foregoing method of inquiry.

317. As already stated (§ 308), the only idea communicated to our minds by the sense of Touch, when exercised in its simplest form, is that of Resistance; when the sensory surface and the substance touched are made to change their place in regard to each other; we obtain the additional notion of Extension or Space. By the various degrees of resistance which the sensory surface encounters, we estimate the hardness or softness of the body; but in this we are assisted by the muscular sense (§ 257), which makes us conscious of the degree of pressure we are employing. By the impressions made upon the papillæ during the movement of the tactile surface over that which is being examined, the roughness, smoothness, or other peculiar characters of the latter are estimated. Our knowledge of *form*, however, is a very complex process, requiring not merely the exercise of the sense of touch, but also great attention to the muscular sensations. It is chiefly, as formerly remarked, in the variety of movements of which the hand of Man is capable, that it is superior to that of any other animal; and it cannot be doubted that this affords a very important means of acquiring information in regard to the external world, and especially of correcting many vague and fallacious notions which we should derive from the sense of sight if used alone. On the other hand, it must be confessed, that our knowledge would have a very limited range, if we could acquire no ideas, except through this sense. It is probably on the sensations communicated through the touch, that the idea of the material world, as something external to ourselves, chiefly rests, but this idea is by no means a direct result of these sensations, being rather an instinctive or intuitive perception excited by them. Every person who directs the least attention to the subject, must perceive how completely different are those notions of the primary or elementary properties of matter, which we base upon the information thus communicated to us, from the sensations themselves; and, as Dr. Alison has justly remarked, "a decisive proof of this being the true representation of this part of our mental constitution, is obtained by attending to the idea of extension or space; which is undoubtedly formed during the exercise of the sense of touch; and is no sooner formed than it 'swells in the human mind to Infinity,' to which certainly no human sensation can bear any resemblance."

318. That the conditions under which certain of the modifications of common sensation operate, are in some respects different from those of ordinary Touch, is very easily shown. Thus, the feeling of tickling is excited most readily in parts which have the least tactual sensibility,—the armpits, flanks, and soles of the feet; whilst in the points of the fingers it cannot be excited. Moreover, the nipple is very moderately endowed with ordinary sensibility; yet by a particular kind of irritation, a very strong feeling may be excited through it. Again, in regard to temperature, it is remarked by Weber that the left hand is more sensitive than the right; although the sense of touch is undoubtedly the most acute in the latter. He states that, if the two hands, previously of the same temperature, be plunged into separate basins of warm water, that in which the left hand is immersed will be felt as the warmest, even though its temperature is somewhat lower than that of the other. In regard to the sensations of heat and cold he points out another curious fact,—that a weaker impression made on a large surface

seems more powerful than a stronger impression made on a small surface: thus, if the forefinger of one hand be immersed in water at 104°, and the whole of the other hand be plunged in water at 102°, the cooler water will be thought the warmer; whence the well known fact, that water in which a finger can be held, will scald the whole hand. Hence it also follows, that minute differences in temperature, which are imperceptible to a single finger, are appreciated by plunging the whole hand into the water; in this manner, a difference of one-third of a degree may readily be detected, when the same hand is placed successively in two vessels. The judgment is more accurate when the temperature is not much above or below the usual heat of the body; just as sounds are best discriminated when neither very acute nor very grave.

319. The improvement in the sense of Touch, in those persons whose dependence upon it is increased by the loss of other senses, is well known; this is doubtless to be in part attributed (as already remarked) to the increased attention which is given to the sensations, and in part to the increased development of the organ itself, resulting from the frequent use of it. The case of Saunderson, who, although he lost his sight at two years old, became Professor of Mathematics at Cambridge, is well known; amongst his most remarkable faculties, was that of distinguishing genuine medals from imitations, which he could do more accurately than many connoisseurs in full possession of their senses. The process of the acquirement of the power of recognizing elevated characters by the touch, is a remarkable example of this improveability. When a blind person first commences learning to read in this manner, it is necessary to use a large type; and every individual letter must be felt for some time, before a distinct idea of its form is acquired. After a short period of diligent application, the individual becomes able to recognize the combinations of letters in words, without forming a separate idea of each letter, and can read line after line, by passing the finger over each, with considerable rapidity. Now when this power is once thoroughly acquired, it is found that the size of the type may be gradually diminished; and this seems to indicate, that the sensations themselves are rendered more acute, by the frequent application of them in this direction. As an instance of the correct notions which may be conveyed to the mind, of the forms and surfaces of a great variety of objects, and of the sufficiency of these notions for accurate comparison, the Author may mention the case of a blind friend of his own, who has acquired a very complete knowledge of Conchology, both recent and fossil; and who is not only able to recognize every one of the numerous specimens in his own Cabinet, but to mention the nearest alliances of a Shell previously unknown to him, when he has thoroughly examined it by his touch. Many instances are on record of the acquirement, by the blind, of the power of distinguishing the colours of surfaces which were similar in other respects; and, however wonderful this may seem, it is by no means incredible. For it is to be remembered that the difference of colour depends upon the position and arrangement of the particles composing the surface, which render it capable of reflecting one ray whilst it absorbs all the rest; and it is quite consistent with what we know from other sources, to believe that the sense of touch may become so refined, as to communicate a perception of such differences.

320. The examples of peculiar acuteness of this sense, which we occasionally meet with among the lower animals, are very interesting when viewed in connection with its improveability in Man. It was found by Spallanzani, that Bats, when deprived of sight, and (as far as possible) of hearing and smelling also, still flew about with equal certainty and safety,

avoiding every obstacle, passing through passages only just large enough to admit them, and flying about places previously unknown, with the most unerring accuracy, and without coming into collision with the objects near which they passed. He also stretched threads in various directions across the apartment, with the same result. So astonished was he at these curious facts, that he was led to attribute the phenomenon to the possession of a sixth sense, unknown to Man. Cuvier was the first to appreciate the real value of these experiments, as affording a proof of the existence of a vast expansion of the most exquisite tactile sensibility, over the whole surface of the flying membrane; the naked surface and delicate structure of which appear well adapted to constitute the seat of so important a function. From this view, therefore, it would appear that it is by means of the pulsation of the wings on the air, that the propinquity of solid bodies is perceived, through the manner in which the air reacts on their surface. It is curious that the instance which (so far as we at present know) is most analogous to this, should be met with among the inhabitants of the deep. It is a fact well known to Whale-fishers, especially to those who pursue the Spermaceti Whale, that these animals have the power of communicating with each other at great distances. It has often been observed, for example, that, when a straggler is attacked, at the distance of several miles from a shoal, a number of its fellows bear down to its assistance, in an almost incredibly short space of time. It can scarcely be doubted, then, that the communication must be made through the medium of the vibrations of the water, excited by the struggles of the animal, or perhaps by some peculiar movements especially designed for this purpose, and propagated through the fluid to the large cutaneous surface of the distant Whales; and this idea is fully confirmed by the fact, that the nerves which proceed to the skin, pass through the inner layers of blubber with scarcely any subdivision, but spread out into a network of extreme minuteness, as soon as they arrive at the surface.

Sense of Taste.

321. That this sense may be really considered as a peculiar modification of that of Touch, appears from several considerations. In the first place, the *actual contact* of the object of sense, with the organ through which the impression is received, is here necessary; and this is the case in regard to no other sense. Moreover the intimate structure of the organ is nearly the same in both instances. Again, it appears from the considerations formerly alluded to (§ 228), that there is no special nerve of taste; the gustative impressions made upon the front of the tongue being conveyed by the lingual branch of the fifth pair; whilst those made upon the back of the organ are conveyed by the glosso-pharyngeal. The first of these nerves also ministers to ordinary tactile sensibility; the second appears to convey the impressions which produce nausea.* The papillæ of the tongue are essentially the same in structure with those of the skin; although Anatomists have classified them, according to their differences of form and situation, there is no definite physiological evidence that they possess corresponding varieties of endowment, although this is quite possible. As a general rule, it is a neces-

* Indeed it may be questioned whether the glosso-pharyngeal is really a nerve of *taste* at all; since the experiments which would indicate that it is so may be explained upon the supposition that *nausea*, rather than real gustative sensibility, was induced by the substances applied to the tongue after division of the lingual branch of the fifth pair.

sary condition of the sense of taste, that the object should either be in a state of solution, or should be soluble in the moisture covering the tongue; if this be not the case, or if the tongue be dry, a simple feeling of contact is all that is produced. As in the case of touch, the idea of the character of the sapid body is very imperfect, unless it is made to move over the gustative surface; and thus the taste is very much heightened by the compression and friction of the substance between the tongue and the palate. From all these circumstances it appears indisputable, that a very strong analogy exists between Taste and Touch; indeed it may be questioned whether they are not in reality more closely allied, than is the sense of Temperature with that of Resistance.

322. Although the tongue seems to be the chief seat of Gustative sensibility, yet this is also possessed, though in a less degree, by the palate. But it is to be remarked that the sensations produced by most sapid substances are of a complex kind; and are in great part due to the organ of Smell. Of this any one may convince himself, by closing the nostrils, and inspiring and expiring through the mouth only, when holding in the mouth, or even rubbing between the tongue and the palate, some sapid substance; of which the taste is then scarcely recognised, although it is immediately perceived, when its effluvia are drawn into the nose. It is well known too, that, when the sensibility of the Schneiderian membrane is blunted by inflammation (as in an ordinary cold in the head), the power of distinguishing flavours is very much diminished. In fact some physiologists are of opinion that *all* our knowledge of the *flavour* of sapid substances is received through the Smell; and this is not improbably true: but it is to be remembered, that, besides *flavour*, a sapid body may excite various other sensations, as those of irritation and pungency; and of these it seems to be the true function of the sensory surface of the mouth to take cognizance. Such sensations are evidently not far removed from those of ordinary touch; and correspond with those which may be excited in the nostrils through the medium of the fifth pair. Taken in its ordinary compound acceptation, the sense of Taste has for its object to direct us in the choice of food, and to excite the flow of the mucus and saliva, which are destined to aid in the preparation of the food for Digestion. Among the lower Animals, the instinctive perceptions connected with this sense are much more remarkable than our own; thus an omnivorous Monkey will seldom touch fruits of a poisonous character, although their taste may be agreeable; and animals whose diet is restricted to some one kind of food will decidedly reject all others. As a general rule it may be stated that substances of which the taste is agreeable to us are useful in our nutrition; and vice versâ: but there are many signal exceptions to this.

323. Like other senses, that of Taste is capable of being rendered more acute by education; and this on the principles already laid down in regard to touch. The experienced wine-taster can distinguish differences in age, purity, place of growth, &c., between liquors that to ordinary judgments are alike; and the epicure can give an exact determination of the spices that are combined in a particular sauce, or of the manner in which the animal, on whose flesh he is feeding, was killed. As in the case of other senses, moreover, impressions made upon the sensory surface remain there for a certain period; and this period is for the most part longer than that which is required for the departure of the impressions made upon the eye, the ear, or the organ of smell. Every one knows how long the taste of some powerful substances remains in the mouth; and even of those which make less decided impressions, the sensation remains to such a degree, that

it is difficult to compare them at short intervals. Hence if a person be blindfolded, and be made to taste substances of distinct but not widely different flavours (such as various kinds of wine or of spirituous liquors), one after another in rapid succession, he soon loses the power of discriminating between them. In the same manner, the difficulty of administering very disagreeable medicines may be sometimes got over, by either previously giving a powerful aromatic, or combining the aromatic with the medicine; its strong impression in both cases preventing the unpleasant taste from exciting nausea.

Sense of Smell.

324. Of the nature of odorous emanations, the Natural Philosopher is so completely ignorant, that the Physiologist cannot be expected to give a definite account of the mode in which they produce sensory impressions. Although it may be surmised that they consist of particles of extreme minuteness, dissolved as it were in the air, and although this idea seems to derive confirmation from the fact that most odorous substances are volatile, and vice versâ,—yet the most delicate experiments have failed to discover any diminution in weight, in substances that have been impregnating with their effluvia a large quantity of air for several years (§ 104, *note*); and there are some volatile fluids, such as water, which are entirely inodorous. The Schneiderian or Pituitary membrane is the seat of the sense of smell; but it is probable that every part of it is not equally endowed with the faculty of distinguishing *odours*, which is a very different power from that of becoming sensible of irritation from them. The olfactory nerves cannot be traced to the membrane covering the middle and inferior spongy bones, or to that which lines the different sinuses, these parts of the surface being supplied by the fifth pair only: and it is a matter of common experience, that we cannot distinguish faint odours, unless, by a peculiar inspiratory effort, we draw the air charged with them to the upper part of the nose. In animals living in the air, it is a necessary condition of the exercise of the sense of smell, that the odorous matter should be transmitted by a respiratory current through the nostrils; and that the membrane lining these should be in a moist state. Hence, by breathing through the mouth, we may avoid being affected by odours, even of the strongest and most disagreeable kind; and in the first stage of a catarrh, when the ordinary mucous secretion is suspended, the sense of smell is blunted from this cause, as it afterwards is from the excess in the quantity of the fluid, which prevents the odoriferous effluvia from coming into immediate relation with the sensory extremities of the nerves. Hence we may easily comprehend, that section of the fifth pair, which exercises a considerable control over the secretions, will greatly diminish the acuteness of the smell; and it will have the further effect of preventing the reception of any impressions of irritation from acrid vapours, which are entirely different in their character from true odorous impressions, and which are not transmitted through the olfactory nerve (§ 220). The nasal passages may indeed be considered as having, in the air-breathing Vertebrata, two distinct offices; they constitute the organ of smell, through the distribution of the olfactory nerve upon a part of their surface; but they also constitute the portals of the respiratory organs, having for their office to take cognisance of the aeriform matter which enters them, and to give warning of that which would be injurious; this latter function is performed by the fifth pair, as it is by the par vagum in the glottis. It is through this nerve that the act of sneezing is excitable;

the evident purpose of which is the ejection of a strong blast of air through the nasal passages, in such a manner as to drive out any offending matter they may contain.

325. The importance of the sense of smell among many of the lower animals, in guiding them to their food, or in giving them warning of danger, and also in exciting the sexual feelings, is well known. To Man its utility is very subordinate under ordinary circumstances; but it may be greatly increased when other senses are deficient. Thus, in the well-known case of James Mitchell, who was deaf, blind, and dumb, from his birth, it was the principal means of distinguishing persons, and enabled him at once to perceive the entrance of a stranger. It is recorded that a blind gentleman, who had an antipathy to cats, was possessed of a sensibilty so acute in this respect, that he perceived the proximity of one that had been accidentally shut up in a closet adjoining his room. Among Savage tribes, whose senses are more cultivated than those of civilized nations, more direct use being made of the powers of observation, the scent is almost as acute as in the lower Mammalia; it is asserted by Humboldt that the Peruvian Indians in the middle of the night can thus distinguish the different races,—whether European, American Indian, or Negro. The agreeable or disagreeable character assigned to particular odours, is by no means constant amongst different individuals. Thus, Müller remarks that to many persons, as to himself, mignonette does not smell very sweet, but rather herb-like; and that the smell of burnt horn, which is generally much disliked, is thought agreeable by some. Many of the lower animals pass their whole lives in the midst of odours, which are to Man (in his civilized condition at least) in the highest degree revolting; and will even refuse to touch food until it is far advanced in putridity. It more frequently happens in regard to odours and savours, than with respect to other sensory impressions, that habit makes that agreeable, and even strongly relished, which was at first avoided; the taste of the epicure for game that has acquired the *fumet*,—for olives,—for assafœtida, &c. are instances of this. As to the length of time during which impressions made upon the organ of smell remain upon it, no certain knowledge can be obtained. It is difficult to say that the effluvia have been completely removed from the nasal passages; since it is not improbable that the odorous particles (supposing such to exist) are absorbed or dissolved by the mucous secretion; it is probably in this manner that we may account for the fact, well known to every medical man, that the cadaverous odour is frequently experienced for days after a post-mortem examination.*

Sense of Vision.

326. The objects of this sense are bodies which are either in themselves luminous, or which become so by reflecting the light that proceeds from others. Whether their light is transmitted by the actual emission of rays, or by the propagation of undulations analogous to those of sound, is a question at present keenly debated amongst Natural Philosophers; but it is of little consequence to the Physiologist which is the true solution; since it is only with the laws which actually regulate the transmission of light, that he is concerned. These laws it may be desirable here briefly to recapitulate.

* This may partly be attributed also to the effluvia adhering to the dress. It has been remarked that *dark* cloths retain these more strongly than light.

327. Every point of a luminous body sends off a number of rays, which diverge in every direction, so as to form a cone, of which the luminous point is the apex. So long as these rays pass through a medium of the same density, they proceed in straight lines; but, if they enter a medium of different density, they are *refracted* or bent,—*towards* the perpendicular to the surface at the point at which they enter, if they pass from a rarer into a denser medium,—and *from* the perpendicular, when they pass from a denser medium into a rarer. It is easily shown to be a result of this law, that, when parallel rays passing through air fall upon a convex surface of glass, they will be made to converge, so as to meet at the opposite extremity of the diameter of the circle of which the curve forms part. If, instead of continuing in the glass, they pass out again, through a second convex surface, of which the direction is the reverse of the first, they will be made to converge still more, so as to meet in the centre of curvature. Rays which are not parallel, but are diverging from a focus, are likewise made to converge to a point or focus; but this point will be more distant from the lens, in proportion as the object is nearer to it, and the angle of divergence consequently greater. The rays diverging from every point of a luminous object are thus brought to a corresponding focus; and the places of all these foci hold exactly the same relation to each other, with that of the points from which the rays diverged; so that a perfect image of the object is formed upon a screen held in the focus of the lens. This image, however, will be inverted; and its size, in proportion to that of the object, will depend upon their respective distances from the lens. If their distances be the same, their size will also be the same; if the object be distant, and the image near, the latter will be much the smaller; and vice versâ.

328. There are two circumstances, however, which interfere with the perfection of an image thus formed by a convex lens. The one is, that, if the lens constitute a large part of the sphere from which it is taken, the rays which fall near its margin are not brought to a focus at the same point with those which pass through its centre, but at a point nearer the lens. This difference, which must obviously interfere greatly with the distinctness of the image, is termed *spherical aberration;* it may be corrected by the combination of two or more lenses, of which the curvatures are calculated to balance one another, in such a manner that all the rays shall be brought to the same focus; or by diminishing the aperture of the lens by means of a stop or diaphragm, in such a manner that only the central part of it shall be used. The latter of these methods is the one employed, where the diminution in the amount of light transmitted is not attended with inconvenience. The nearer the object is to the lens (and the greater, therefore, the angle of divergence of its rays), the greater will be the spherical aberration, and the more must the aperture of the diaphragm be contracted in order to counteract it. The other circumstance that interferes with the distinctness of the image, is the unequal refrangibility of the differently-coloured rays, which together make up white or colourless light; the violet being more bent from their course than the blue, the blue more than the yellow, and the yellow more than the red; the consequence of which will be, that the violet rays are brought to a focus much nearer to the lens than the blue, and the blue nearer than the red. If a screen be held to receive the image in the focus of any of the rays, the others will make themselves apparent as fringes round its margin. This difference is termed *Chromatic Aberration*. It is corrected in practice by combining together lenses of different substances, of which the

dispersive power (that is, the power of separating the coloured rays) differs considerably. This is the case with flint and crown glass, for instance; the dispersive power of the former being much greater than that of the latter, whilst its refractive power is nearly the same: so that, if a convex lens of crown glass be united with a concave of flint whose curvature is much less, the dispersion of the rays effected by the former will be counteracted by the latter, which diminishes in part only its refractive power.

329. The Eye may be regarded as an optical instrument of great perfection, adapted to produce, on the expanded surface of the Optic nerve, a complete image or picture of luminous objects brought before it; in which the forms, colours, lights and shades, &c., of the object are all accurately represented. By the different refractive powers of the transparent media through which the rays of light pass, and by the curvatures given to their respective surfaces, both the Spherical and Chromatic aberrations are corrected in a degree sufficient for all practical purposes; so that, in a well-formed eye, the picture is quite free from haziness, and from false colours. The power by which it adapts itself to variations in the distance of the object, so as to form a distinct image of it whether it be six inches, six yards, or six miles off, is extremely remarkable, and cannot be regarded as hitherto completely explained. It is obvious that, if we fix upon any distance as that for which the eye is naturally adjusted (say 12 or 14 inches, the distance at which we ordinarily read), the rays proceeding from an object placed nearer to the eye than this would not be brought to a focus upon the retina, but would converge towards a point behind it; whilst, on the contrary, the rays from an object at a greater distance would meet before they reached the retina, and would have again diverged from each other when they impinge upon it: so that in either case, vision would be indistinct. Now two methods of adaptation suggest themselves to the Optician. Either he may vary the distance between the refracting surface and the screen on which the image is formed, in such a manner that the latter shall always be in the focus of the converging rays; or, the distance of the screen remaining the same, he may vary the convexity of his lens, in such a manner as to adapt it to the distance of the object. It is not improbable that both of these methods are employed in the eye, though no distinct evidence has been obtained of the operation of either. Several hypotheses have been proposed, to account for the phenomenon: it is easily proved that no one of them can alone be true; but it cannot be readily shown that any of them is entirely false: and it would not seem unlikely, therefore, that all may participate, in various degrees, in the effect. The following are the principal of these.—1. An alteration in the form of the globe of the eye by the action of the muscles, so that its antero-posterior diameter may be increased or diminished.*—2. A change in the convexity of the cornea. This might be very well connected with the last; since, if the globe were converted into a spheroid of which the antero-posterior diameter would be the longest, the curvature of the cornea would be increased; whilst, if the antero-posterior diameter were shortened, the curvature would be diminished.—3. Change of position of the crystalline lens, by means of the ciliary processes.—4. Change of figure of the lens itself. That one or both of these are concerned in the effect, would appear from the fact well known to every oculist, that,

* The influence of the muscles in altering the form of the globe may be better comprehended, now that we know the mode in which this is kept in its place in the front of the orbit, by a fascia passing behind it, and attached anteriorly to the lids.

after the removal of a cataract, the power of adapting the eye to distances is greatly diminished.—5. Change in the aperture of the pupil; the mode in which this could assist in accommodating the eye to variations of distance is not very obvious.

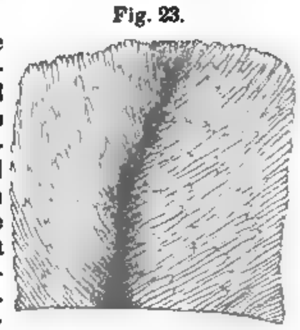
330. Some curious circumstances relative to the connection between the optical adaptation of the eye to distances, and the changes in the direction of the axes of the two eyes, have been pointed out by Müller. When both eyes are fixed upon an object, their axes must converge (as formerly explained) so as to meet in it. The nearer the object, the greater must be the degree of convergence; and when the object is brought within the ordinary distance of distinct vision, the convergence must very rapidly increase. Now this is precisely what takes place in regard to alterations in the focus of the eye; for little change is required when the object is made to approach from a considerable distance to a moderate distance; but, when it is brought near the eye, the focus must be considerably lengthened, or the convexity of the eye increased, to cause the rays to meet on the retina. Hence it may be surmised that the same cause is acting to produce both changes; but that the convergence of the axes is itself in any way the occasion of the alteration of the focus of the eye, is shown by the fact, that the adaptation is as perfect, in a person who only possesses or uses one eye, as it is when both are employed, and also by the power which is possessed by some persons, of altering the focus of the eye by an effort of the will, whilst the convergence remains the same. In regard to the adaptation of the eyes to varying distances, it is further to be remarked that, when an object is being viewed as near to the eye as it can be distinctly seen, the pupil contracts in a considerable degree. The final cause of this change is evidently to exclude the outer rays of the cone or pencil, which, from the large angle of their divergence, would fall so obliquely on the convex surface of the eye, as to be much affected by the spherical aberration; and to allow the central rays only to enter the eye, so as to preserve the clearness of the image. The channel through which it is effected is evidently the same, as that by which the convergence of the eyes is produced,—namely the inferior branch of the third pair of nerves, to the action of which the sensations upon the retina form the stimulus, in the same manner as they do to the ordinary variation in the diameter of the pupil under the influence of light.

331. The ordinary forms of defective vision, which are known under the names of *myopia* and *presbyopia*, or short-sightedness and long-sightedness, are entirely attributable to defects in the optical adaptation of the eye. In the former, its refractive power is too great; the rays from objects at the usual distance are consequently brought too soon to a focus, so as to cross one another and diverge before they fall upon the retina; whilst the eye is adapted to bring to their proper focus on the retina, only those rays which were previously diverging at a large angle, from an object in its near proximity. Hence a short-sighted person, whose shortest limit of distinct vision is not above half that of a person of ordinary sight, can see minute objects more clearly; his eyes having, in fact, the same magnifying power which those of the other would possses, if aided by a convex glass that would enable him to see the object distinctly at the shorter distance. But as the myopic structure of the eye incapacitates its possessor from seeing objects clearly at even a moderate distance, it is desirable to apply a correction; and this is done, simply by interposing a concave lens, of which the curvature is properly adapted to compensate for the excess of that of the organ itself between the object and the eye. On the other hand, in the presbyopic eye, the curvature and refractive power are not sufficient to bring to a focus on-

the retina, rays which were previously divergent in a considerable or even in a moderate degree; and indistinct vision in regard to all near objects is, therefore, a necessary consequence, whilst distant objects are well seen. This defect is remedied by the use of convex lenses, which make up for the deficiency of the curvature. We commonly meet with myopia in young persons, and with presbyopia in old; but this is by no means the invariable rule; for even aged persons are sometimes short-sighted; and long-sightedness is occasionally met with amongst the young. In choosing spectacles, for the purpose of correcting the errors of the eye, it is of great consequence not to make an over-compensation; for this has a tendency to increase the defect, besides occasioning great fatigue in the employment of the sight. It may be easily found when a glass of the right power has been selected, by inquiring of the individual whether it alters the apparent size of the objects, or only renders them distinct. If it alter the size (increasing it if it be a convex lens, and diminishing it if it be a concave), its curvature is too great; whilst if it do not disperse the haze, it is not sufficiently powerful. In general it is better to employ a glass which somewhat under-compensates the eye, than one which is of a curvature at all too high; since, with the advance of years in elderly persons, a progressive increase in power is required; and, as young persons grow up to adult age, they should endeavour to dispense with the aid of spectacles.

332. Many other interesting inquiries, respecting the action of the eye as an optical instrument, suggest themselves to the physical philosopher; but the foregoing are the chief in which the Physiologist is concerned, and we shall now proceed, therefore, to consider the share which the retina and optic nerve perform in the phenomena of vision. The Optic Nerve, at its entrance into the eye, divides itself into numerous small fasciculi of ultimate fibrils; and these spread themselves out, and inosculate with each other by an exchange of fibrils, so as to form a net-like plexus, which is the outer layer of the true retina. From this plexus, in which the fibres are lying in the plane of the surface of the vitreous humour, a very large number of fibrils arise in a direction perpendicular to that surface, so as all to be directed towards the centre of the eye. These pass through a delicate layer of cellular tissue, containing a minute plexus of blood-vessels; and from this every fibril receives a sheath, which envelopes its extremity, thus forming a minute papilla. The surface of the retina in contact with the vitreous humour, is entirely composed of these papillæ, which are closely set together. In the retina of the Frog, the diameter of the ultimate nervous fibres is stated by Treviranus at about $\frac{1}{5400}$th of an inch; whilst that of the papillæ is about $\frac{1}{3110}$th of an inch.

Fig. 23.

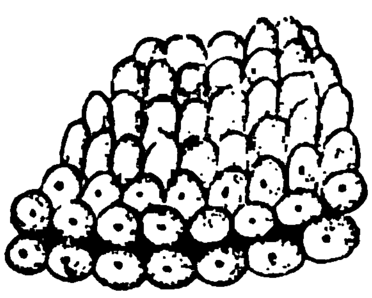


Part of the retina of a Frog seen from the outer surface. Magnified 300 times. (After Treviranus.)

In Birds and Mammalia, however, the papillæ, as well as the nervous fibrils, are much smaller; in the former the diameter of the papillæ is stated at from about $\frac{1}{12700}$th to $\frac{1}{3330}$th of an inch; in the rabbit at $\frac{1}{7700}$th of an inch; and in Man at from the $\frac{1}{5000}$th to $\frac{1}{3400}$th of an inch.* An attempt has been

* This is the diameter assigned by Weber to what he terms the *globules* of the Retina; there can be little doubt, however, that these are identical with the papillæ, since the latter are very apt to separate, in eyes which are examined even a short time after death, from the fibres beneath.

Fig. 24.



Papillæ of the retina of the Frog, seen from the side turned towards the vitreous humour; the four higher rows are seen sideways. Magnified 300 times. (After Treviranus.)

made to show, that the size of the papillæ determines that of the smallest object which can be seen by the unaided eye; and it is a curious fact, that the calculation long ago made by Smith, in regard to the size of the most minute sensitive point upon the retina, founded upon the dimensions which the image of the minutest visible object will possess, coincides exactly with the measurement of Weber. There is no doubt, however, that, under favourable circumstances, the eye will take cognisance of objects much smaller than those on which Smith's calculation was founded. The following statements on this interesting subject comprehend the result of numerous inquiries recently made by Ehrenberg, with the view of establishing the limits of Human Vision, as a datum from which to calculate the ultimate power of the Microscope.*

333. In opposition to the generally-received opinion, Ehrenberg arrived at the conclusion that, in regard to the extreme limits of vision, there is little difference amongst persons of ordinarily good sight, whatever may be the focal distance of their eyes. The smallest square magnitude usually visible to the naked eye, either of white particles on a black ground, or of black upon a white or light-coloured ground, is about the $\frac{1}{363}$ of an inch. It is possible, by the greatest condensation of light, and excitement of the attention, to recognise magnitudes between the $\frac{1}{463}$th and $\frac{1}{540}$th of an inch; but without sharpness or certainty. Bodies which are smaller than these cannot be discerned when single with the naked eye, but may be seen when placed in a row. Particles which powerfully reflect light, however, may be distinctly seen, when not half the size of the least of the foregoing; thus, gold dust† of the fineness of $\frac{1}{1123}$th of an inch may be discerned with the naked eye in common daylight. The delicacy of vision is far greater for *lines* than for single particles; opaque threads of $\frac{1}{4900}$th of an inch in diameter may be discerned with the naked eye, when held towards the light. Such threads are about half the diameter of the Silkworm's fibre. It is evident, from these facts, that the images of such particles formed upon the retina must be considerably smaller than the diameter of the papillæ. Still it is by no means improbable that, when we are looking at a continuous surface, the diameter of the papillæ will regulate our power of distinguishing minute parts of that surface; since, as Weber justly remarks, two impressions falling upon one of these points can scarcely affect the sensorium otherwise than with one sensation. The degree in which the attention is directed to them, has a great influence on the readiness with which very minute objects can be perceived; and Ehrenberg remarks that in this respect there is a much greater difference amongst individuals, than there is in regard to the absolute limits of vision. Many persons can distinctly see such objects, when their situation is exactly pointed out to them, who cannot otherwise distinguish them; and the same is the case with persons of acuter perception, with respect to objects at distances greater than those at which they can see most clearly. "I myself," says Ehrenberg, "cannot see $\frac{1}{2700}$th of an inch, black on white, at twelve inches distance; but having found it at from four to five inches distance,

* Taylor's Scientific Memoirs. Vol. i. p. 576.

† Ehrenberg mentions that he obtained the finest particles of gold, by scraping gi brass; by filing pure gold, he always obtained much coarser particles.

can remove it to twelve inches, and still see the object plainly." Similar phenomena are well known in regard to a balloon, or a faint star, in a clear sky; or a ship in the horizon: we easily see them after they have been pointed out to us; but the faculty of rapidly descrying depends on the habit of using the eyes in search of such objects (§ 313).

334. The sense of Vision depends, in the first place, on the transference to our minds of the picture which is formed upon the retina; this picture puts us in possession of the outlines, lights and shades, colours, and relative positions, of the objects before us; and all the ideas respecting the real forms, distances, &c. of bodies, which we found upon these data, must be considered in the light of perceptions, either instinctive or acquired. Many of these are derived through the combination, in our minds, of the visual sensations with those derived from the sense of touch. Thus, to take a most simple illustration, the idea of *smoothness* is one essentially tactile; and yet it constantly occurs to us, on looking at a surface which reflects light in a particular manner. But if it were not for the association which experience leads us to form, of the connection between *polish* as seen by the *eye*, and *smoothness* as felt by the *touch*, we should not be able to determine, as we now can do, the existence of both these qualities, from an impression communicated to us through either sense singly. The general fact that, in Man, the greater part of those notions of the external world, by which his actions in the adult state are guided, are acquired by the gradual association of the sensations communicated by the sight and by touch, is substantiated by amply-sufficient evidence. This evidence is chiefly derived from observations made upon persons born blind, to whom sight has been communicated by an operation, at a period of life which enabled them to give an accurate description of their sensations. The case recorded by Cheselden is one of the most interesting of these. The youth (about 12 years of age) for some time after tolerably distinct vision had been obtained, saw every thing *flat* as in a picture; simply receiving the consciousness of the impressions made upon his retina; and it was some time before he acquired the power of judging by his sight, of the real forms and distances of the objects around him. An amusing anecdote recorded of him shows the complete want of natural or intuitive connection which there is in Man, between the ideas formed through visual and tactile sensations. He was well acquainted with a Dog and a Cat by *feeling;* but could not remember their respective characters when he *saw* them. One day, when thus puzzled, he took up the Cat in his arms, and felt her attentively, so as to associate the two sets of ideas; and then, setting her down, said, "So, puss, I shall know you another time." A similar instance has come under the Author's own knowledge; but the subject of it was scarcely old enough to present phenomena so striking. One curious circumstance was remarked of him, which fully confirms (if confirmation were wanting) the view here given. For some time after the sight was tolerably clear, the lad preferred finding his way through his father's house, to which he had been quite accustomed when blind, by touch rather than by sight,—the use of the latter sense appearing to perplex rather than to assist him: but, when learning a new locality, he employed his sight, and evidently perceived the increase of facility which he derived from it.

335. The question has been proposed, whether a person born blind, who was able by the sense of touch to distinguish a cube from a sphere, would, on suddenly obtaining his sight, be able to distinguish them by the latter sense. This question was answered by Locke in the negative; and probably with justice. It is no real objection to such a reply, that a new-born

animal seeks the nipple of its mother, when informed of its proximity by sight; for all that is indicated by this fact is, that the sensation excites an intuitive feeling of desire, which gives rise to movements adapted to gratify it. Such instinctive actions, founded upon intuitive perceptions, are, as already pointed out, much more numerous in the lower animals than in the higher, and in the young of the Human species than in the adult (§ 259); and they do not afford any proof that definite notions, such as we acquire, of the forms and properties of external objects, are possessed by the animals which exhibit them. We shall now examine, a little more in detail, into the means by which we gain such notions, and the data on which they are founded.

336. The first point to be determined is one which has been a fruitful source of discussion,—the cause of *erect vision*, the picture upon the retina being inverted. Many solutions of it have been attempted; but they are for the most part rather specious than really satisfactory. That which has been of late years the most in vogue, is founded upon what was styled the Law of Visible Direction, which has been supported by Sir D. Brewster, and other eminent Philosophers. This law affirms, that every object is seen in the direction of the perpendicular to that point of the retina, on which its image is formed; or, in other words, that, as all the perpendiculars to the several points of the inner surface of a sphere meet in the centre, the line of direction of any object is identical with the prolonged radius of the sphere, drawn from the point at which its image is made upon the retina. Upon close examination, however, it is found that this law cannot be optically correct; since the lines of direction cross each other at a point much anterior to the centre of the globe; as may be determined by drawing a diagram upon a large scale, and laying down the course of the rays received by the eye, according to the curvatures and refractive powers of its different parts. In this manner it has been determined by Volkmann, that the lines of direction cross each other in a point a little behind the crystalline lens; and that they will thus fall at such different angles on different points of the retina, that no general law can be laid down respecting them. It may be questioned, moreover, whether any such law would afford any assistance in explaining the phenomenon; since, after all, it is requisite to assume an intuitive application of it, in supposing the mind to derive its ideas of the relative situations of objects from the supposed line of direction. A much simpler and more direct explanation may be given. We must remember that which we have had occasion to notice in regard to all the other senses, —the broad line of distinction between the sensation and the perception or elementary notion; and this is still more clearly shown by the complete absence of any relation, but such as experience developes, between the perceptions derived through the sight, and those acquired from the touch. Hence there is no more difficulty in understanding, that an inverted picture upon the retina should convey to us a notion of the external world, which harmonizes with that acquired through the sense of touch, than there is in comprehending the formation of any of those intuitive perceptions of animals, which are so much more removed from the teachings of our own experience (§ 290). It is justly remarked by Müller that, "if we do see objects inverted [or rather, if the picture on the retina is inverted] the only proof we can possibly have of it, is that afforded by the study of the laws of Optics; and, if every thing is seen reversed, the relative position of the objects remains unchanged. Hence it is, also, that no discordance arises between the sensations of inverted vision and those of touch, which perceives every thing in its erect position; for the images of all objects, even of our

own limbs, on the retina, are equally inverted, and therefore maintain the same relative position. Even the image of our hand, when used in touch, is inverted." From what has been stated it would appear quite conceivable, that a person just endowed with sight, should not at first know by his visual powers, whether a pyramid placed before his eyes is the same body, and in the same position, as one with which he has become acquainted by the touch; and, if this be admitted, the inference necessarily follows, that the notion of *erectness*, which we form by the combined use of our eyes and our hands, is really the product of experience in ourselves, whilst it is probably innate or intuitional in the lower animals.

337. The cause of single vision with the two eyes has, in like manner, been the subject of much discussion; since the mode in which we are affected by the two simultaneous impressions, is quite different from that in which we derive our knowledge of external things through the other senses. Some have even asserted that we do not really employ both eyes simultaneously, but that the mind is affected by the image communicated by one only; and this idea might seem to be confirmed by the fact heretofore mentioned (§ 313) respecting the alternate use of the two eyes, when they are looking through two differently-coloured media. But it is easily disproved in other ways. It will presently be shown that all our estimates of the forms of bodies depend on the combination by the mind of the images simultaneously transmitted by the two eyes; and our knowledge of distances is in great part obtained in like manner. The condition of Single Vision has been already stated (§ 253) to be probably this,—that the two images of the object should be formed on parts of the two retinæ which are *accustomed* to act in concert; and reasons were given for the belief, that *habit* is the chief means by which this conformity is produced. There can be no doubt, however, that double images are continually being conveyed to our minds; but that from their want of force and distinctness, and from the attention being fixed on something else, we do not take cognisance of them. This may be shown by a very simple experiment. If two fingers be held up before the eyes, one in front of the other, and vision be directed to the more distant, so that it is seen singly, the nearer will appear double; while, if the nearer one be regarded more particularly, so as to appear single, the more distant will be seen double. A little consideration will show, therefore, that our minds must be continually affected with sensations which cannot be united into the idea of a single image; since, whenever we direct the axes of our eyes towards any object, every thing else will be represented to us as double, although we do not ordinarily perceive this, from our minds being fixed upon a clear and distinct image, and disregarding, therefore, the vague undefined images formed by objects at a different focus. Of this it is very easy to convince oneself. It is moreover evident from this experiment, that double vision cannot result from want of symmetry in the position of the images upon the retina, to which some have attributed it; for it answers equally well, if the line of the two fingers be precisely in front of the nose, so that the inclination of both eyes towards either object is equal; the position of the images of the second object must then be at the same distance on each side from the central line of the retina, and yet they are represented to the mind as double. It is, moreover, easily shown that, in the lower animals whose orbits are not directed forwards as in us, but sideways in a greater or less degree, whenever an object is so situated as to be seen by both eyes, the points of the two retinæ on which its images are formed, must be very far from possessing this symmetry.

338. Many attempts have been made to explain the phenomena of single vision, by the decussation of the optic nerves; but, from the facts which have been adverted to, it seems evident that no *material* influence can affect the process; the fusion of the two images into one being entirely a mental operation. In regard to this decussation, it is stated by Mr. Mayo (Med. Gaz. Nov. 5, 1841) that the optic nerve in Man consists of three tracts; of which the internal one is strictly commissural, connecting together the two retinæ anteriorly, and the two optic ganglia posteriorly; the middle tract decussates, and is believed by Mr. M. to supply that part of the retina which lies on the inner side of each ball, between its anterior border and the insertion of the optic nerve; whilst the external tract does not decussate, but passes on to supply the exterior portion of the retina on the same side. Thus the right optic nerve supplies the right side of each ball; whilst the left supplies the left side. On the other hand, in most of the Osseous Fishes, the decussation is complete; each nerve passing entirely to the eye of the opposite side. From these and other data, Mr. M. concludes that each nerve is used in looking towards the opposite side. This is evidently true of the Osseous Fishes, whose two eyes, being directed sideways, have two entirely different spheres of vision. And it is true also of Man (if Mr. M.'s account of the distribution of the nerve be correct), since, when we look at an object held directly in front of the face, at the level of the eyes, and at the nearest point for distinct vision, almost the whole of that portion of the *right* retina, which lies to the outside of the entrance of the optic nerve, is directed to the left; and the exactly different, complementary, or inner portion of the *left* retina, which is supplied by the *same nerve*, is likewise directed to the left. On this supposition, all the rays entering the two eyes from any one point, will be brought to a focus on fibrils belonging to the same nerve; though these are in Man, as in other animals whose spheres of vision are nearly or partly coincident, distributed to distinct visual organs.*

339. We shall next consider the mode in which our notion of the *solid forms* and relative projection of objects is acquired; on which great light has recently been thrown by the interesting experiments of Mr. Wheatstone.† It is perfectly evident, both from reason and experience, that the flat picture upon the retina, which is the only object of our sensation, could not itself convey to our minds any notion, but that of a corresponding plane surface. In fact, the notion of solidity, which would be formed by a person who had never had the use of more than one eye, would entirely depend upon the combination of his visual and tactile sensations. This idea is fully confirmed by the case already referred to as recorded by Cheselden. The first visual idea formed by the youth was, that the objects around him formed a flat surface, which touched his eyes, as they had previously been in contact with his hands; and after this notion had been corrected by the educa-

* The late Dr. Wollaston was subject to a curious affection of vision, which consisted in his not being able to see more than half of an object,—the loss being sometimes on one side, and sometimes on the other. The author has met with several cases of this disorder, which has been termed *hemiopia*. Dr. W. thought that they might be explained by the decussation of the optic nerve; but Mr. Mayo states that he has known instances of a parallel affection, involving alternately the centre and circumference of the retina, and therefore not attributable to any such structural arrangement.

[Since this paragraph was written, it has been pointed out to the author that a view of the objects of the commissure of the optic nerves, nearly the same as that of Mr. Mayo, has been given by Mr. Solly, in his very useful work on the Brain, p. 263.—C.]

† Philosophical Transactions, 1838.

tion of his sight by his touch, he fell into the converse error of supposing that a picture, which was shown to him, was the object itself represented in relief on a small scale. But where both eyes are employed, it has been ascertained by Mr. Wheatstone that they concur in exciting the perception of solidity or projection, which arises from the combination in the mind of two different images. It is easily shown that any near object is seen in two different modes by the two eyes. Thus let the reader hold up a thin book, in such a manner that its back shall be exactly in front of his nose, and at a moderate distance from it; he will observe, by closing first one eye and then the other, that his perspective view of it (or the manner in which he would represent it on a plane surface) is very different, according to the eye with which he sees it. With the right eye he will see its right side, very much foreshortened; with the left he will gain a corresponding view of the left side; and the apparent angles, and the lengths of the different lines, will be found to be very different in the two views. On looking at either of these views singly, no other notion of solidity can be acquired from it, than that to which the mind is conducted, by the association of such a view with the touch of the object it represents. But it is capable of proof, that the mental association of the two different pictures upon the retinæ, does of itself give rise to the idea of solidity. This proof is afforded by Mr. Wheatstone's ingenious instrument, the Stereoscope.

340. The Stereoscope essentially consists of two plane mirrors, inclined with their backs to one another at an angle of 90°. If two perspective drawings of any solid object, as seen at a given distance with the two eyes respectively, be placed before these mirrors, in such a manner that their images shall be made to fall upon the corresponding parts of the two retinæ, in the same manner as the two images formed by the solid object itself would have done, the mind will perceive, not a single representation of the object, nor a confused union of the two, but a body projecting in relief, —the exact counterpart of that from which the drawings were made. Mr. Wheatstone further shows by means of the Stereoscope, that similar images, differing to a certain extent in magnitude, when presented to the corresponding parts of the two retinæ, give rise to the perception of a single object, intermediate in size between the two monocular pictures. Were it not for this, objects would appear single, only when at an equal distance from both eyes, so that their pictures upon the retina are of the same size; which will only happen when it is directly in front of the median line of the face. Again, if pictures of dissimilar objects be simultaneously presented to the two eyes, the consequence will be similar to that which is experienced when the rays come to the eye through two differently coloured media;—the two images do not coalesce, nor do they appear permanently superposed upon one another; but at one time one image predominates to the exclusion of the other, and then the other is seen alone; and it is only at the moment of change that the two seem to be intermingled. It does not appear to be in the power of the will, Mr. Wheatstone remarks, to determine the appearance of either; but, if one picture be more illuminated than the other, it will be seen during a larger proportion of the time. Many other curious experiments with this simple instrument are related by Mr. Wheatstone; and they all go to confirm the general conclusion, that the combination of the images furnished by the two eyes is a mental act, resulting from an inherent law of our psychical constitution; and that our preceptions of the solidity and projection of objects near enough to be seen in different views with the two eyes, result from this cause. In regard to distant objects, however, the difference in the images formed by the two

eyes is so slight, that it cannot aid in the determination; and hence it is that, whilst we have no difficulty in distinguishing a picture, however well painted, from a solid object, when placed near our eyes (since the idea which might be suggested by the image formed on one eye, will then be corrected by the other), we are very liable to be misled by a delineation, in which the perspective, light and shade, &c. are faithfully depicted, if we are placed at a distance from it, and are prevented from perceiving that it is *but* a picture. In this case, however, a slight movement of the head is sufficient to undeceive us; since by this movement a great change would be occasioned in the perspective view of the object, supposing it to possess an uneven surface; whilst it scarcely affects the image formed by a picture. In the same manner, a person who only possesses one eye obtains, by a slight motion of his head, the same idea of the form of a body, which another would acquire by the simultaneous use of his two eyes.

341. The appreciation of the *distance* of objects may be easily shown to be principally derived from the association in the mind of visual and tactual sensations, assisted, in regard to near objects, by the muscular sensations derived from the convergence of the eyes. Thus, an infant, or a person who has but recently acquired sight, evidently forms very imperfect ideas regarding the distance of objects; and it is only after long experience that a correct notion is formed. The assistance which is given by the joint use of both eyes, is evident from the fact, that, if we close one eye, we are unable to execute with certainty many actions which require a precise appreciation of the distance of near objects,—such as threading a needle, or snuffing a candle. In regard to distant objects, our judgment is chiefly founded upon their apparent size, if their actual size be known to us; but, if this is not the case, and if we are so situated that we cannot form an estimate of the intervening space, we principally form our estimate from the greater or less distinctness of their colour and outline. Hence this estimate is liable to be greatly affected by varying states of the atmosphere; as is well known to every one who has visited warmer latitudes. The extreme clearness of the air sometimes brings into an apparently near proximity, a hill that rises beyond some neighbouring ridge (the intervening space being hidden, so as not to afford any datum for the estimate of the distance of the farther hill), and which, by a slight haziness, is carried to three or four times the degree of apparent remoteness. It is probable that, in the lower animals, the perception of distance is much more than it is in ourselves.

342. Our estimate of the real *size* of an object is manifestly connected with that of its distance. The *apparent* size is dependent upon the angle at which its rays diverge, to impinge upon the cornea; this angle increases with the proximity, and diminishes with the remoteness, of the object. Our estimate of the comparative size of near objects, of whose distances we can become aware by the inclination of optic axes, is much more correct than that which we form, when one or both are far removed; since, when we are uncertain as to its distance, we cannot form a judgment of the real size of a body, from the angle at which its rays diverge. Hence our estimate of the size of objects even moderately distant is much influenced by states of the atmosphere. Thus, if we walk across a common in a fog, child approaching us appears to have the size of a man, and a man seems like a giant; since the indistinctness of the outline excites in the mind the idea of distance; and an object seen under a given visual angle at a distance must of necessity be much larger than one, of which the apparent size is the same, but which is much nearer. The want of innate power in Man

form a true conception of either size or distance, is well shown by the effect produced on the mind unprepared for such delusions, by a skilfully painted picture, the view of which is so contrived, that its distance from the eye cannot be estimated in the ordinary manner; the objects it represents are invested by the mind with their real sizes and respective distances, as if their real image was formed upon the retina.*

343. From all these considerations we are led to perceive the truth of the quaint observation made by Dr. Brown,—that "vision is, in fact, the art of seeing things which are invisible;" that is, of acquiring information, by means of the eye, which is neither contained in the sensations of sight themselves, nor logically deducible from the intimations which those sensations really convey. We cannot too constantly bear in mind, in treating of this subject, that we do not take cognisance by our optic nerves, as we do by the nerves of touch, of material bodies themselves, but of the pictures or images formed by those objects; and whatever be the notions suggested by the picture, *that* can never be transformed into any thing else. These notions appear to be in the lower animals entirely of an intuitional or instinctive character; in Man they are so in a much less degree; and although it is impossible to come to a precise conclusion on the subject, from the want of sufficient data, it is indubitable that a large part of the knowledge of the external world, which he derives in the adult condition from the use of his eyes alone, is really dependent upon the early education of his perceptive powers, in which process, the sensations conveyed by different organs are brought to bear on one another.

344. The persistence, during a certain interval, of impressions made upon the retina, gives rise to a number of curious visual phenomena. The prolongation of the impression will be governed in part by its previous duration. Thus, when we rapidly move an ignited point through a circle, the impression itself is momentary, and remains but for a short time; whilst, if we have been for some time looking at a window, and then close our eyes, the impression of the dark bars traversing the illuminated space is preserved for several seconds. Such phenomena can here be only briefly adverted to. One of these is the combination into one image of two or more objects presented to the eye in successive movements; but these must be of a kind which can be united, otherwise a confused picture is produced. Thus in a tittle toy, called the Thaumatrope, which was introduced some years ago, the two objects were painted on the opposite sides of a card,—a bird, for instance, on one, and a cage in the other; and, when the card was made (by twisting a pair of strings) to revolve about one of its diameters, in such a manner as to be alternately presenting the two sides to the eye at minute intervals, the two pictures were blended, the bird being seen in the cage. A far more curious illusion, however, was that first brought into notice by Mr. Faraday; who showed that, if two toothed wheels, placed one behind the other, be made to revolve with equal velocity, a stationary spectrum will be seen; whilst if one be made to revolve more rapidly than the other, or the number of teeth be different, the spectrum also will revolve. The same takes place when a single wheel is made to revolve before a mirror; the wheel and its image answering the purpose of the two wheels in the former case. On this principle a number of very ingenious toys have been constructed; in some of these, the same figure or object is

* This delusion has been extremely complete in some of those who have seen the panoramic view of London in the Coliseum. A lively and interesting account of it is given in the Journal of the Parsee Shipbuilders, who recently visited England.

seen in a variety of positions; and the impressions of these, passing rapidly before the eye, give rise by their combination to the idea, that the object is itself moving through these positions. Similar illusions may be produced in regard to colour.

345. When the Retina has been exposed for some time to a strong impression of some particular kind, it seems less susceptible of feebler impressions of the same kind. Thus, if we look at any brightly luminous object, and then turn our eyes on a sheet of white paper, we shall perceive a dark spot upon it; the portion of the retina which had been affected by the bright image not being able to receive an impression from the fainter rays reflected by the paper. The dark spectrum does not at once disappear, but assumes different colours in succession,—these being expressions of the states through which the retina passes, in its transition to the natural condition. If the eye has received a strong impression from a coloured object, the spectrum exhibits the complementary colour;* thus, if the eye be fixed for any length of time upon a bright red spot on a white ground, and be then suddenly turned so as to rest upon the white surface, we see a spectrum of a green colour. The same explanation applies to the curious phenomenon of coloured shadows. It may not unfrequently be observed at sunset, that, when the light of the sun acquires a bright orange colour from the clouds through which it passes, the shadows cast by it have a blue tint. Again, in a room with red curtains, the light which passes through these produces green shadows. In both instances, a strong impression of one colour is made on the general surface of the retina; and at any particular spots, therefore, at which the light is colourless but very faint, that colour is not perceived, its complement only being visible. The correctness of this explanation is proved by the fact, that, if the shadow be viewed through a tube in such a manner that the coloured ground is excluded, it seems like an ordinary shadow. It is not unlikely that, as Müller suggests, the predominant action of one colour on the retina disturbs (as it were) the equilibrium of its condition, and excites in it a tendency to the development of a state, corresponding to that which is produced by the impression of the complementary colour; for the latter is, according to him, perceived even where it does not exist;—as when the eye, after receiving a strong impression from a coloured spot, and directed upon a completely dark surface or into a dark cavity, still perceives the spectrum. Upon these properties of the eye are founded the laws of harmonious colouring, which have an obvious analogy with those of musical harmony. All complementary colours have an agreeable effect, when judiciously disposed in combination; and all bright colours which are not complementary have a disagreeable effect, if they are predominant: this is especially the case in regard to the simple colours, strong combinations of any two of which, without any colour that is complementary to either of them, are extremely offensive. Painters who are ignorant of these laws, introduce a large quantity of dull grey into their pictures, in order to diminish the glaring effects which they would otherwise produce; but this benefit is obtained by a sacrifice of the vividness and force, which may be obtained in combination with the richest harmony, by a proper attention to physiological principles.

* By the complementary colour is meant, that which would be required to make white or colourless light, when mixed with the original. Red, blue, and yellow, being the primary or elementary colours, red is the complement of green (which is composed of yellow and blue), blue is the complement of orange (red and yellow), and yellow of purple (red and blue), and vice versa in all instances.

346. Some persons, who can perfectly distinguish forms, are deficient, through some original peculiarity in the constitution of the retina, in the power of discriminating colours. This is most commonly seen in regard to the complementary colours, especially red and green; such persons not being able to perceive cherries amidst the leaves on a tree, except by the difference of their form. Several distinct varieties of this affection may be distinguished, however; and these have been classified by Leebeck.*

347. Amongst other curious phenomena of Vision is the vanishing of images which fall at the entrance of the optic nerve, as is shown in the following experiment. Let two black spots be made upon a piece of paper, about four or five inches apart; then let the left eye be closed, and the right eye be strongly fixed upon the left hand spot. If the paper be then moved backwards and forwards, so as to change its distance from the eye, a point will be found at which the right-hand spot is no longer visible; though it is clearly seen when the paper is brought nearer or removed further. In this position of the eye and object, the rays from the right-hand spot cross to the nasal side of the globe, and fall upon the point of the retina, which has just been mentioned. The phenomenon is not confined to that spot, however; nor is it correct to say, as is sometimes done, that the retina is not sensible to light at that point; since, if such were the case, we should see a dark spot in our field of view whenever we use only one eye. The fact is that a similar phenomenon may occur under somewhat different conditions, in any division of the retina, especially in its lateral parts. Thus, if we fix the eye for some time, until it is fatigued, upon a strip of coloured paper lying upon a white surface, the image of the coloured object will in a short time disappear, and the white surface will be seen in its place; the disappearance of the image, however, is only of a few seconds duration. The truth seems to be, that there is a tendency in the retina to the propagation, over neighbouring parts, of impressions which occupy a large proportion of its surface; and that this tendency is the strongest, around the point at which the optic nerve enters, so that the state of this part will generally become similar to that of the surrounding portion of the retina. Hence, when we are using one eye only, we do not perceive any dark spot in the field, but only a portion in which no distinct image is formed of the part of the object before it.

348. Under particular circumstances we may receive a visual representation of the retina itself; as is shown by the experiment of Purkinje. "If, in a room otherwise dark, a lighted candle be moved to and fro, or in a circle, at the distance of six inches before the eyes, we perceive, after a short time, a dark arborescent figure ramifying over the whole field of vision; this appearance is produced by the vasa centralia distributed over the retina, or by the parts of the retina covered by those vessels. There are, properly speaking, two arborescent figures, the trunks of which are not coincident, but on the contrary arise in the right and left divisions of the field, and immediately take opposite directions. One trunk belongs to each eye, but their branches intersect each other in the common field of vision. The explanation of this phenomena is as follows:—By the movement of the candle to and fro, the light is made to act on the whole extent of the retina, and all the parts of the membrane which are not immediately covered by the vasa centralia are feebly illuminated; those parts, on the contrary, which are covered with those vessels cannot be acted on by the light, and are perceived, therefore, as dark arborescent figures. These

* Müller's Physiology, p. 1213.

figures appear to lie before the eye, and to be suspended in the field of vision."* We have thus another demonstration of the fact that, in ordinary vision, the immediate object of our sensation is a certain condition of the retina, which is excited by the formation of a luminous image.

Sense of Hearing.

349. In the Ear as in the Eye, the impressions made upon the sensory nerve are not at once made by the body which originates the sensation; but they are propagated to it through a medium capable of transmitting them. Here too, therefore, we take cognisance by the mind, not of the sonorous object, but of the condition of the auditory nerve; and all the ideas we form of sounds, as to their nature, intensity, direction, &c., must be based upon the changes which they produce in it. The complex contrivances which we meet with in the organ of hearing among higher animals, are evidently intended to give them greater power of discriminating sounds, than is possessed by the lower tribes, in which it is reduced to a form so simple, that it may be questioned whether they can be said to possess an organ of *hearing*, if by this term we imply any thing more than the mere consciousness of sonorous vibrations. There is a considerable difference, however, between the Eye and the Ear, in regard to the special purposes for which they are respectively adapted. In the former we have seen, that the whole object of the instrument was to direct the rays of light received by it in such a manner, as to occasion them to fall upon the expansion of the optic nerve in the same relative position, and with corresponding proportional intensity, with that which they possessed when issuing from the object. We have no reason to believe any thing of this kind to be the purpose of the ear; indeed it would be inconsistent with the laws of the propagation of sound. Sonorous vibrations having the most various directions, and the most equal rate of succession, are transmitted by all media without modification, however numerous their lines of intersection; and wherever these undulations fall upon the auditory nerve, they must cause the sensation of corresponding sounds. Still it is probable that some portions of the complex organ of hearing in Man and in the higher animals, are more adapted than others to receive impressions of a particular character; and that thus we may be especially informed of the direction of a sound by one part of the organ, of its musical tone by another, and of some other of its qualities by a third. In our inquiries into this ill-understood subject, we shall commence with a brief survey of the comparative structure of the organ.

350. The essential part of an Organ of Hearing being obviously a nerve endowed with the peculiar property of receiving and transmitting sonorous undulations, it is by no means indispensable that a special provision should be made for this purpose; since the auditory nerve, if merely in contact with the solid parts of the head, will be affected by the vibrations in which it is continually participating. Hence we must not imagine the sense to be absent, wherever we cannot discover a special organ. It is among the highest only of the Invertebrate animals, that any such special organ presents itself; and then only in a very simple form. Thus in the Crustacea and Cephalopoda, the ear consists of a small cavity excavated in the solid frame-work of the head; this cavity is lined with a membrane, on which the nerve is distributed; and it is filled with a watery fluid. In some

* Muller's Physiology, p. 1163.

instances, the cavity is completely shut in by its solid walls; and the sonorous vibrations can then only be communicated through these: but in the higher forms of this apparatus, there is a small aperture covered with a membrane, upon which the external medium can at once act. In tracing this most simple into the more complex forms, it is at once seen that the cavity corresponds with the *vestibule* of the ear of higher animals, and its opening with the fenestra ovalis. In the lowest Cyclostome Fishes, the organ is but little more complicated; from the vestibule proceeds a single annular passage, which may be considered as a semi-circular canal; and the auditory nerve is distributed minutely upon its lining membrane, as upon that of the vestibule itself. In species a little higher in the scale, two such canals exist; these are present in the Lamprey. And in all the rest of the class, three semi-circular canals are found, holding the same direction in regard to each other as they do in Man. Within the vestibular sac of Fishes are found calcareous concretions, which are pulverulent in the Cartilaginous, but hard and stony in the Osseous tribes; to these the name of Otolithes has been given. Some rudiments of a tympanic cavity may be found in Fishes; but there is no vestige of a cochlea: in several tribes the organ of hearing possesses a peculiar connection with the air-bladder; which appears to be a foreshadowing of the Eustachian tube of higher classes.

351. In the true Reptiles, a considerable advance is constantly to be found in the character of the Ear; a tympanic cavity being added, with a drum and a chain of bones; and a rudiment of the cochlea being generally discoverable. Among the Amphibia, however, which are in so many respects intermediate between the true Reptiles and Fishes, there is a remarkable variation in this respect,—some having a tympanum, and some being completely destitute of it. Wherever a tympanic cavity distinctly exists, there is an Eustachian tube connecting it with the fauces. This cavity, in the true Reptiles, not only possesses the *fenestra ovalis* (or opening into the vestibule) but the *fenestra rotunda* (or opening into the cochlea). The membrana tympani is usually visible externally; but it is sometimes covered by the skin. In Birds the structure of the ear is essentially the same as in the higher Reptiles. A distinct cochlea exists, though its form is not spiral but nearly straight: of its character, however, there can be no doubt; a division into two passages, by a membranous partition on which the nerve is spread out, being evident. Moreover the tympanum communicates with cavities in the cranial bones, which are thus filled with air, and, by increasing the extent of surface, produce a more powerful resonance. There is no external ear, except in a few species of nocturnal Birds. In Mammalia the organ of hearing is usually formed upon the same plan as it presents in Man; in the Monotremata, however, it more approaches that of Birds. The cochlea of the Mammalia in general is a spiral, forming about two turns and a half; the partition which divides its canal is partly osseous, partly membranous; and its two passages communicate with the tympanic cavity and the vestibule respectively. The cavity of the tympanum is very large in some species, extending even into the contiguous bones. All the Mammalia except the aquatic tribes have an external ear; and this is sometimes of an enormous size in proportion to the dimensions of the body, as it is in the Bats. The labyrinth of the higher Vertebrata contains no otolithes.

352. The ultimate terminations of the fibres of the auditory nerve in minute papillæ, are best seen in the lamina spiralis of the cochlea and its

Fig. 25.

Papillæ of the Auditory nerve, on a segment of the spiral lamina of the cochlea of a young Mouse, the lower portion is the osseous, and the higher the membranous part of the lamina. Magnified 300 times. After Treviranus.

membranous prolongation. Much diversity exists, however, as to the interpretation of the appearances there seen; some observers affirming that there are no free or papillary terminations, and that the nervous fibres all return by loops; whilst others state that the papillæ are clearly to be distinguished. The fact appears to be that, as in the retina, the fibres do form a minute plexus; but that fibres are connected with this, which end, or rather commence, in papillæ. The auditory nerve is also very minutely distributed on the membrane lining the vestibule and semicircular canals; and in the ampullæ or dilated extremities of the latter, there are little projections of this membrane internally, which are largely supplied with nerves.

353. In order to gain any definite idea of the uses of different parts of the Ear, it is necessary to bear in mind, that sounds may be propagated amongst solid or fluid bodies in three ways,—by *reciprocation*, by *resonance*, and by *conduction*.—1. Vibrations of reciprocation are excited in a sounding body, when it is capable of yielding a musical tone of definite pitch, and another body of the same pitch is made to sound near it. Thus if two strings of the same length and tension be placed alongside of each other, and one of them be sounded with a violin-bow, the other will be thrown into reciprocal vibration; or if the same tone be produced near the string in any other manner, as by a flute, or a tuning-fork, the same effect will result.—2. Vibrations of resonance are of somewhat the same character; but they occur when a sounding body is placed in connection with any other, of which one or more parts are capable of being thrown into reciprocal vibration, even though the tone of the whole be different, or it be not capable of producing a definite tone at all. This is the case, for example, when a tuning-fork in vibration is placed upon a sound-board; even though the whole board have no definite fundamental note, it will divide itself into a number of parts which will reciprocate the original sound, so as greatly to increase its intensity; and the same sound-board will act equally well, for tuning-forks of several different degrees of pitch. When a smaller body is used for resonance, however, it is essential that there should be a relation between its fundamental note* and that of the sonorous body; otherwise no distinct resonance is produced. Thus, if a tuning-fork in vibration be held over a column of air in a tube, of such a length that the same note would be given by its vibration, its sound will be reciprocated. But if it be held over a pipe, the column of air in which is a multiple of this, the column

* The *fundamental note* of a body is the lowest tone which it will yield, when the whole of it is in vibration together. By dividing the body into two or more distinct parts, it may be made to give a great variety of sounds. Thus, if a stretched string be divided by a bridge into two equal parts, each will sound the octave of the fundamental note, or 8th note above it. If it be divided into three parts, each will give the 12th above the fundamental note; if into four, the 15th or double octave will be heard; if into five, the 17th; if into six, the 19th; if into seven, the 20½th (flat seventh above the second octave); if into eight, the 22nd or triple octave. A string set in vibration has a tendency to sound these harmonics with the fundamental note, by spontaneous division into several distinct segments of vibration, as may be easily made evident, by striking one of the lower keys of the piano, and listening to the sounds heard whilst the fundamental note is dying away.

will divide itself into that number of shorter parts, each of which will reciprocate the original sound, and the total action will be one of resonance.—3. Vibrations of conduction are the only ones by which sounds can strictly be said to be propagated. These are distinguishable into various kinds, into which it is not requisite here to inquire. It should be remarked, however, that all media, fluid, liquid, or solid, are capable of transmitting sound in this manner,—a vacuum being the only space through which it cannot pass. The transmission is usually much more rapid through solid bodies than through liquid, and through liquid than through gaseous. The greatest diminution in the intensity of sound is usually perceived, when a change takes place in the medium through which it is propagated, especially from the aeriform to the liquid.

354. The detailed application of these principles has been most elaborately worked out by Müller; and the following statement of what may be regarded as the present state of our knowledge of the subject, is little more than an abstract of his results. Considering it desirable, in the first place, to establish the conditions under which those animals hear, that are constantly immersed in water, he made a series of experiments, from which he draws the following conclusions:—I. Sonorous vibrations excited in water are imparted with considerable intensity to solid bodies.—II. Sonorous vibrations of solid bodies are communicated with greater intensity to other solid bodies brought in contact with them, than to water; but with much greater intensity to water than to atmospheric air.—III. Sonorous vibrations are communicated from air to water with great difficulty,—with very much greater difficulty than they are propagated from one part of the air to another; but their transition from air to water is much facilitated by the intervention of a membrane extended between them.—IV. Sonorous vibrations are not only imparted from water to solid bodies with definite surfaces which are in contact with the water, but are also returned with increased intensity by these bodies to the water; so that the sound is heard loudly in the vicinity of those bodies, in situations where, if it had its origin in the conducting power of water alone, it would be faint.—V. Sonorous undulations, propagated through water, are partially reflected by the surfaces of solid bodies.—VI. Thin membranes conduct sound in water without any loss of its intensity, whether they be tense or lax. From III., IV., and VI., we learn the mode in which the sound is conducted to the ear in aquatic animals not breathing atmospheric air. The labyrinth of such is either entirely enclosed within the bones of the head, as in the Cephalopoda, and in the Cyclostome and Osseous Fishes; or, its cavity being prolonged to the surface of the body, it is there brought into communication with the conducting medium by means of a membrane, besides receiving the vibrations through the medium of the solids of the body, as is the case in Cartilaginous Fishes and Crustacea. It would seem as if, in the Osseous Fishes, the resonance of the cranial bones in which the labyrinth is imbedded, were sufficient to give the requisite increase of intensity to the sound; whilst in the Cartilaginous orders, the softness of these bones renders some other means necessary. In addition to this, we find in many Fishes a communication with the air-bladder, which indeed seems to have in these little other use. The mode in which this increases by resonance the intensity of the sounds, will appear from the following experimental conclusions.—VII. When sonorous vibrations are communicated from water to air enclosed in membranes or solid bodies, a considerable increase in the intensity of the sound is produced by the resonance of the air thus circumscribed.—VIII. A body of air enclosed in a membrane, and surrounded by

water, also increases the intensity of the sound by resonance, when the sonorous undulations are communicated to it by a solid body.—From these observations it may be concluded that the air-bladder of Fishes, in addition to other uses, serves the purpose of increasing by resonance the intensity of the sonorous undulations communicated from the water to the body of the Fish. Moreover, as the conducting and resonant power of the air in the air-bladder is greater in proportion to its density, the influence of this organ on the perception of sounds will, of course, be greater in deep waters, where the pressure upon it is considerably increased.

355. Most animals living in air are provided with the opening into the vestibule, covered by a thin membrane; and, in the majority of cases, with the tympanic apparatus also. The following experimental results bear upon the manner in which the Ear of such animals is affected by sound.—IX. Sonorous undulations, in passing from air directly into water, suffer a considerable diminution in their strength; while, on the contrary, if a tense membrane exists between the air and water, the sonorous undulations are communicated from the former to the latter medium with great intensity.—X. The sonorous vibrations are also communicated without any perceptible loss of intensity from the air to the water, when to the membrane forming the medium of communication there is attached a short solid body, which occupies the greater part of its surface, and is alone in contact with the water.—XI. A small solid body, fixed in an opening by means of a border of membrane, so as to be movable, communicates sonorous vibrations, from air on one side, to water or the fluid of the labyrinth on the other, much better than solid media not so constructed. But the propagation of sound to the fluid is rendered much more perfect, if the solid conductor thus occupying the opening is by its other end fixed to the middle of a tense membrane, which has atmospheric air on both sides.—The fact stated in IX. is evidently one of great importance in the physiology of hearing; and fully explains the nature of the process in those animals which receive the sonorous vibrations through air, but have no tympanic apparatus. In X. we have the elucidation of the action of the fenestra ovalis, and of the movable plate of the stapes which occupies it, in animals living in air but destitute of tympanic apparatus; this is naturally the case in many Amphibia; and it may happen as the result of disease in the Human subject. In XI. we have a very interesting demonstration of the purpose and action of the tympanum, in the more perfect forms of the auditory apparatus. We are now prepared to inquire, in somewhat more detail, into the action of the different parts of this; and it will be better to commence with that of the internal ear, the accessory organs being afterwards considered.

356. The object of the *Membrana Tympani* is evidently to receive the sonorous undulations from the air, in such a manner as to be thrown by them into a reciprocal vibration, which is to be communicated to the chain of bones. This membrane is in its usual state rather lax than tense; and this laxity is found by experiment to be, for a small membrane, the best condition for the propagation of ordinary sounds. This is easily rendered sensible in one's own person; for an increased tension may be given to the membrana tympani, either by holding the breath and forcing air into the Eustachian tube, so as to distend it from within, or by exhausting the cavity, so as to cause the external air to make increased pressure upon it. In either case the hearing is found immediately to become indistinct. It is observed, however, that grave and acute sounds are not equally affected by this action; for the experimenter renders himself deaf to grave sounds, whilst acute sounds are heard even more distinctly than before. This fact

is easily understood, by referring to the laws of acoustics already referred to. The greater the tension to which the membrana tympani is subjected, the more acute will be its fundamental tone; and as no proper reciprocation can take place in it to any sound *lower* than its fundamental tone, its power of repeating perfectly the vibrations proper to the deeper notes will diminish. The nearer a sound approaches to the fundamental note proper to the tense membrane, the more distinctly will it be heard. On the other hand, when the membrane is in its natural lax condition, its fundamental note is very low, and it is capable of repeating a much greater variety of sounds; for, when it receives undulations of a higher tone than those to which the whole membrane would reciprocate, it divides itself into distinct segments of vibration, which are separated by lines of rest; and every one of these reciprocates the sound,* at the same time rendering it more intense by multiplication. These facts enable us to understand the influence of the tensor tympani muscle, in modifying the tension of the membrane, and thus causing it to vibrate in reciprocation to sounds having a great variety of fundamental notes. Moreover, the fact that some persons are deaf to grave sounds, whilst they readily hear the more acute, is thus accounted for. The tensor tympani, like the iris, is probably excited to operation by a reflex action; and it is by no means improbable that one of its functions may be, to prevent the internal ear from being too violently affected by loud sounds, by putting the membrana tympani into such a state of tension, as not readily to reciprocate them.

357. The uses of the Tympanic cavity are very obvious. One of its purposes is to render the vibrations of the membrane quite free; and the other, to isolate the chain of bones, in such a manner as to prevent their vibrations from being weakened by diffusion through the surrounding solid parts. As to the objects of the Eustachian tube, however, opinions have been much divided. From the experiments of Müller it appears that it does not increase the intensity of sound, but that it prevents a certain degree of dullness which would attend it if the cavity of the tympanum were completely closed; of this dullness we are conscious, when any tumefaction of the fauces causes an occlusion of the extremity of the tube. It has been supposed that, among other uses, this canal serves for the conduction of the speaker's voice to his ears; but this is certainly not the case in any considerable degree; for, when the Eustachian tubes are obstructed by disease, the patient hears his own voice well, though other sounds are indistinct; and it is easily shown that its transmission is chiefly accomplished in other ways. The common idea is, that it serves the same purpose with the hole in an ordinary drum, the effect of which is ordinarily supposed to be the removal of the impediment to the vibrations of the membrane, that would be offered by the complete enclosure of the air within. It does not appear, however, that any such impediment is really offered; and the effect of the hole in the drum seems rather to be the communication, to the ear of the auditor, of the sonorous vibrations of the contained air; which are thus transmitted directly through the atmosphere, instead of being weakened by

* This is very easily proved by experiments on a membrane stretched over a resonant cavity; if light sand be strewed upon it, and a strong musical tone be produced in its vicinity, the membrane will immediately be set in vibration, not as a whole (unless its fundamental note be in unison with that sounded), but in distinct segments, of which every one reciprocates the sound; from the vibrating parts, the sand will be violently thrown off; but it will settle on the intermediate lines of rest, forming a variety of curious figures, which are known as the *nodal* lines.

transmission through the walls of the instrument. Hence there is no real analogy in the two cases. The principal object of the Eustachian tube (which is always found where there is a tympanic cavity) seems to be the maintenance of the equilibrium between the air within the tympanum and the external air; so as to prevent inordinate tension of the membrana tympani, which would be produced by too great or too little pressure on either side, and the effect of which would be imperfection of hearing. It also has the office of conveying away mucus secreted in the cavity of the tympanum, by means of cilia vibrating on its lining membrane; and the deafness consequent on occlusion of this tube is in part explicable, by the accumulation which will then take place in the tympanum.

358. From what has been stated, it is evident that sonorous undulations taking place in the air, will be propagated to the fluid contained in the labyrinth, through the tympanum, the chain of bones, and the membrane of the fenestra ovalis to which the stapes is attached, without any loss, but rather an increase, of intensity. Why water should be chosen as the medium through which the impression is to be made upon the nerve, it is impossible for us to say with any thing like certainty, in our present state of ignorance as to the physical character of that impression. But, the problem being to communicate to water the sonorous undulations of air, the experimental results already detailed satisfactorily prove that,—whilst this may be accomplished in a degree sufficient for the wants of the inferior animals, by the simple interposition of a tense membrane between the air and the fluid,—the tympanic apparatus of the higher classes is most admirably adapted for this purpose. The fenestra ovalis is not, however, the only channel of communication between the tympanum and the labyrinth; for there is, in most animals, a second aperture, the fenestra rotunda, leading into the cochlea, and simply covered with a membrane. It is generally supposed that, the labyrinth being filled with a nearly incompressible fluid, this second aperture is necessary to allow of the free vibration of that fluid,—the membrane of the fenestra rotunda being made to bulge out, as that of the fenestra ovalis is pushed in. It may, however, be easily shown by experiment, as well as by reference to comparative anatomy, that no such contrivance is necessary; for sonorous undulations may be excited in a non-elastic fluid, completely enclosed within solid walls at every part, except where these are replaced by the membrane through which the vibrations are propagated; and this is precisely the condition, not only of the aquatic animals, but even of Frogs, in which last a tympanic apparatus exists without a second orifice into the labyrinth. Moreover it is certain that the vibrations of the air in the cavity of the tympanum must of themselves act upon the membrane of the fenestra rotunda; and this is perhaps the most direct manner in which the fluid in the cochlea will be affected; although it will ultimately be thrown into much more powerful action by the transmission of vibrations from the vestibule. For it has been satisfactorily determined by experiment (XII.), that vibrations are transmitted with very much greater intensity to water, when a tense membrane, and a chain of insulated solid bodies capable of free movement, are successively the conducting media than when the media of communication between the vibrating air and the water are the same tense membrane, air, and a second membrane:—or, to apply this fact to the organ of hearing, the same vibrations of the air act upon the fluid of the labyrinth with much greater intensity, through the medium of the chain of auditory bones and the fenestra ovalis, than through the medium of the air of the tympanum and the membrane closing the fenestra rotunda.—The fenestra rotunda is not to be considered as having

any peculiar relation with the cochlea; since, in the Turtle tribe, the former exists without the latter.

359. In regard to the functions of particular parts of the labyrinth, no certainty can be said to exist. From the experimental results already stated, it appears likely that, the greater the extension of the cavity into the dense substance of the bone, the greater will be the resonance communicated to the fluid, and thence transmitted to the nerves exposed to its influence. It is commonly supposed that the Semi-circular Canals have for their peculiar function the reception of the impressions by which we distinguish the direction of sounds; and it is certainly a powerful argument in support of this view, that, in almost every instance in which these parts exist at all, they hold the same relative position to each other as in Man, their three planes being nearly at right angles to one another. The idea, however, must be regarded as a mere speculation, the value of which cannot be decided without an increased knowledge of the laws according to which sonorous vibrations are transmitted. Regarding the special function of the Cochlea, there is precisely the same uncertainty. This part of the organ is peculiar in one respect,—that the expansion of the auditory nerve is here spread out (upon the lamina spiralis) in closer proximity with the bone itself, than it is in any other part of the labyrinth; so that the vibrations of the bone will be more directly communicated to the nerve. It is not easy to see, however, what can be the peculiar object of this disposition, in regard to the function of hearing. By M. Dugès it is surmised that by the cochlea we are especially enabled to estimate the *pitch* of sounds, particularly of the voice; and he adduces in support of this idea, the fact that the development of the cochlea follows a very similar proportion with the compass of the voice. This is much the greatest in the Mammalia; less in Birds; and in Reptiles, which have little true vocal power, the cochlea is reduced to its lowest form, disappearing entirely in the Amphibia. That there should be an acoustic relation between the voice and ear of each species of animal, cannot be regarded as improbable; but the speculation of M. Dugès can at present only be received as a stimulus to further inquiry.

360. We have now to consider the functions of the accessory parts,—the External Ear, and the Meatus. The Cartilage of the external ear may propagate sonorous vibrations in two ways,—by reflection, and by conduction. In reflection, the concha is the most important part, since it directs the reflected undulations towards the tragus, whence they are thrown into the auditory passage. The other inequalities of the external ear cannot promote hearing by reflection; and the purpose of the extension of its cartilage is evidently to receive the sonorous vibrations from the air, and to conduct them to its point of attachment. In this point of view, the inequalities become of importance; for those elevations and depressions upon which the undulations fall perpendicularly will be affected by them in the most intense degree; and in consequence of the varied form and position of these inequalities, sonorous undulations, in whatever direction they may come, must fall advantageously upon some of them. The functions of the Meatus appear to be threefold. The sonorous undulations entering from the atmosphere are propagated directly, without dispersion, to the membrana tympani:—the sonorous undulations received on the external ear are conveyed along the walls of the meatus to the membrana tympani:—the air which it contains, like all insulated masses of air, increases the intensity of sounds by resonance. That, in ordinary hearing, the direct transmission of atmospheric vibrations to the membrana tympani is the principal means of exciting

the reciprocal vibrations of the latter, is sufficiently evident; the undulations which directly enter the passage will pass straight on to the membrane; whilst those that enter obliquely will be reflected from side to side, and at last will fall obliquely on the membrane, thus perhaps contributing to the notion of direction. The power of the lining of the meatus to conduct sound from the external ear is made evident by the fact, that, when both ears are close stopped, the sound of a pipe having its lower extremity covered by a membrane, is heard more distinctly when it is applied to the cartilage of the external ear itself, than when it is placed in contact with the surface of the head. The resonant action of the air in the tube is easily demonstrated by lengthening the passage by the introduction of another tube; the intensity of external sounds, and also that of the individual's voice, is then much increased.

361. Many facts prove, however, that the fluid of the labyrinth may be thrown into vibration in other ways than by the tympanic apparatus. Thus in Osseous Fishes, this is the only manner in which hearing can take place. There are many persons, again, who can distinctly hear sounds which are thus transmitted to them; although, through some imperfection of the tympanic apparatus, they are almost insensible to those which they receive in the ordinary way. It is evident, where this is the case, that the nerve must be in a state fully capable of functional activity; and, on the other hand, where sounds cannot thus be perceived, there will be good reason to believe that the nerve is diseased.

362. A single impulse communicated to the Auditory nerve, in any of the foregoing modes, seems to be sufficient to excite the momentary sensation of sound; but most frequently a series of such impulses is concerned, there being but few sounds which do not partake, in a greater or less degree, of the character of a *tone*. Any continuous sound or tone is dependent upon a succession of such impulses; and its acuteness or depth is governed by the rapidity with which they succeed one another. It is not difficult to ascertain by experiment what number of such impulses or undulations are required, to give every tone which the ear can appreciate. Thus, if a circular plate, with a number of apertures at regular intervals, be made to revolve over the top of a pipe through which air is propelled, a succession of short *puffs* will be allowed to issue from this; and, if the revolution is sufficiently rapid, these impulses will unite into a definite tone. In the same manner, if a spring be fixed near the edge of a revolving toothed wheel, in such a manner as to be caught by every tooth as it passes, a succession of *clicks* will be heard; and these too, if the revolution of the wheel be sufficiently rapid, will produce a tone. The number of apertures in the plate which pass the orifice of the pipe in a given time, or the number of teeth which pass the spring, being known, it is easy to see that this must be the number of impulses required to produce the given tone. Each impulse produces a double vibration,—forwards and backwards;* hence the number of impulses is always half that of the single vibrations. The maximum and minimum of the intervals of successive pulses still appreciable by the ear as determinate sounds, have also been determined by M. Savart, more satisfactorily and more accurately than had previously been done. If the intensity is great, sounds are still audible which result from the succession of 24,000 impulses in a second; and this, probably, is not the extreme limit in acuteness of sounds perceptible by the ear. From some observations of Dr. Wollaston's, it seems probable that the ears of different individuals are

* This is seen when a string is put in vibration, by pulling it out of the straight line.

differently constituted in this respect,—some not being able to hear very acute tones produced by insects or even Birds, which are distinctly audible to others. Again, the sound resulting from 16 impulses per second, is not, as has been usually supposed, the lowest appreciable note; on the contrary, M. Savart has succeeded in rendering tones distinguishable, which were produced by only 7 or 8 impulses in a second; and continuous sounds of a still deeper tone could be heard, if the individual pulses were sufficiently prolonged. In regard, however, to the precise time during which a sonorous impression remains upon the retina, it is difficult to procure exact information, since it departs more gradually than do visual impressions. This is certain, however,—that it is much longer than the interval between the successive pulses in the production of tones; since it was found by M. Savart, that one or even several teeth might be removed from the toothed wheel without a perceptible break,—showing that, when the tone was once established, the impression of it remained during an intermission of some length.

363. The Ear may, like the Eye, vary considerably, as regards general acuteness, amongst different individuals; and its power may be much increased by practice. A part of this increase depends, however, as in other instances, upon the greater attention which its fainter indications receive; but a part, also, upon increased use of the organ. The power of hearing very faint sounds is as different from the power of distinguishing musical tones, as the power of discerning very minute objects, or of seeing with very faint degrees of light, is from that of distinguishing colours. Many persons are altogether destitute of what is termed a musical ear: whilst others are endowed with it in a degree which is a source of great discomfort to them, since every discordant sound is a positive torment. The power of distinguishing the *direction* of sounds appears to be, in Man at least, for the most part acquired by habit. It is some time before the infant seems to know any thing of the direction of noises which attract his attention. Now although there can be no question that this perception is acquired by attention to certain variations in the impression made upon the nerve, through the medium either of the tympanic apparatus, or of the bones of the head, yet it is equally evident that there can be nothing in these variations themselves adequate to excite the idea, and that it must therefore be either intuitive or acquired by habit. This is a consideration of some importance in regard to the similar question as to the sense of Visual direction. In some cases we are probably assisted by the relative intensity of the sensations communicated by the two ears respectively. The idea of the *distance* of the sonorous body is another acquired perception, depending principally upon the loudness or faintness of the sound, when we have no other indications to guide us. In this respect, there is a great similarity between the perception of distance of an object, through the Eye, by its size, and through the Ear by the intensity of its sound. When we know the size of the object, or are acquainted with the usual intensity of its sound, we can judge of its distance; and, vice versâ, when we know its distance, we can at once form an idea of its real from its apparent size, and of its real strength of tone from that which affects our ears. In this manner, the mind may be affected with corresponding deceptions through both senses; thus, in the Phantasmagoria, the figure is gradually diminished whilst its distance remains the same, and it appears to the spectators to recede,—the illusion being more complete, if its brightness be at the same time diminished; and the effect of a distant full military band gradually approaching, may be alike given by a corresponding *crescendo* of concealed instruments. It is upon

the complete imitation of the conditions which govern our ideas of the intensity and direction, as well as of the character, of sounds, that the deceptions of the Ventriloquist are founded.

364. Some facts of much interest have lately been acertained, in regard to an occasional variation in the rapidity of the perception of sensory impressions received through the Eye and through the Ear. These facts are the result of comparisons made amongst different astronomical observers, who may be watching the same visual phenomena, and *timing* their observations by the same clock; for it has been remarked that some persons see the same phenomenon a third or even half a second earlier than others. There is no reason to suppose from this, however, that there is any difference in the rate of transmission of the sensory impressions in the two nerves. The fact seems rather to be, that the sensorium does not readily perceive two different impressions with equal distinctness; and that, when several impressions are made on the nerves at the same time, the mind takes cognisance of one only, or perceives them in succession. When, therefore, both sight and hearing are directed simultaneously to one object, the communication of the impression through one sense will necessarily precede that made by the other. The interval between the two sensations is greater in some persons than in others; for some can receive and be conscious of many impressions, seemingly at the same moment, whilst in others a perceptible space must elapse.

365. Amongst other important offices of the power of Hearing, is that of supplying the sensations by which the voice is regulated. It is well known that those who are born entirely deaf are also dumb,—that is, destitute of the power of forming articulate sounds; even though not the least defect exist in their organs of voice. Hence it appears that the vocal muscles can only be guided in their action by the sensations received through the Ears, in the same manner as other muscles are guided by the sensations received through themselves (§ 399). On this point, more will be said hereafter.

CHAPTER V.

OF MUSCULAR CONTRACTILITY.

366. The Nervous System has no power of occasioning movement in any part of the body, save by exciting to contraction certain structures to which the term *Muscular* is given. That a tissue should possess within itself the property of contractility on the application of a stimulus, is no more wonderful than that another should be capable of conveying sensory or motor influences, or another of separating a peculiar secretion from the blood. Such contractile tissues are found in Vegetables as well as in Animals; and instances of their operation have been already referred to (§ 13). The only essential difference between the contractility* of Muscular Fibre,

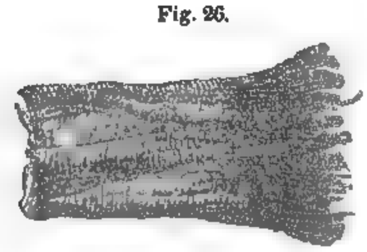
* The peculiar operation of this property in Muscular Fibre, the ordinary contraction of which alternates with relaxation, has occasioned the distinctive term *Irritability* to be applied to it. This term has been employed, however, in so many different senses (being, by some Physiologists, used almost synonymously with the more general one of Vitality), that it seems desirable to avoid adopting it for such a purpose.

and that of the cells of the Sensitive Plant, is that the former can be excited by the stimulus of innervation, as well as by those of a physical or chemical nature, which will act upon the latter. Muscular structure, as heretofore remarked, is employed in the Animal body, not only as the instrument of the operation of the Nervous System upon the external world,—in which respect alone its action can be said to form part of the Functions of Animal Life,—but also to execute many of those interior movements, which the peculiar conditions of Animal existence require for its own maintenance, such as the propulsion of the food along the alimentary canal; and that of the blood through the vascular system. The muscles concerned, however, in these operations, which are so *immediately* connected with the maintenance of the Organic functions, differ essentially from those strictly forming part of the apparatus of Animal life, both in their own structure, and in the manner in which their contractility is called into operation. The former are (like the contractile tissues of Plants) much more susceptible than the latter of being excited to action by a stimulus immediately applied to themselves, and are with difficulty shown to be in any degree under the influence of nerves (§ 201); whilst the latter are readily thrown into violent contraction by a stimulus conveyed to them through the nervous system. Hence a physiological distinction may be made between these two groups of muscles; which is fully borne out by differences in the structure and arrangement of their component parts. By some, the two classes have been spoken of as those of Involuntary and Voluntary Muscles; but this distinction is not correct; since every muscle ordinarily termed voluntary is susceptible of being called into action involuntarily. It is better to found the distinction upon their nearer or more remote concern in the functions of Organic Life; those which are immediately involved in their maintenance, and over which the will can never exert any influence,—the Heart, and Muscular coat of the Intestinal Canal, for instance,—being designated as the Muscular System of Organic Life; and those which can be employed by the Nervous System to execute the commands of the will, being included in the Muscular System of Animal life. The structure peculiar to the latter will be first described; as it is evidently that which is most characteristic of Muscle.

Muscles of Animal Life.

367. When we examine an ordinary Muscle (from one of the extremities for example) with the naked eye, we observe that it presents a fibrous appearance; and that the fibres are arranged with great regularity in the direction in which the muscle is to act. Upon further examination it is found, that these fibres are united together in *fasciculi* or bundles of larger or smaller size, by means of cellular tissue; and when the Microscope is applied to the smallest fibre which can be seen with the naked eye, it is seen itself to consist of a fasciculus, composed of a number of cylindrical fibres lying in a parallel direction, and closely bound together. These fibres present two sets of markings or *striæ*;—one set longitudinal,—the other transverse or annular. By more closely examining these *fibres*, when separated from

Fig. 26.



Fasciculus of Fibres of Voluntary Muscle; the fibres separated at one end, into brush-like bundles of fibrillæ. After Baly.

each other, it is seen that each may be resolved into *fibrillæ*, which, so far as at present known, are the ultimate elements of muscular structure. These fibrillæ are sometimes made evident, by drawing apart the two ends of a fasciculus, so that the fibres are torn; the separated extremities of these are then frequently split into distinct fibrillæ, so that the composition of the fibre becomes at once evident. These fibrillæ are bound together, in the perfect condition of the fibre, by a very delicate tubular sheath, which seems to answer to the tube of nervous fibre. This cannot always be readily brought into view; but it is occasionally seen with great distinctness; thus, when the two ends of a fibre are drawn apart, the contained fibrils will sometimes separate without the rupture of the sheath, which then becomes evident; and during the act of contraction, it may sometimes be observed to rise up in wrinkles upon the surface of the fibre, as seen in Fig. 31. This sheath is quite distinct from the cellular tissue which binds the fibres into fasciculi; and it has been termed, for the sake of distinction, the *Sarcolemma.** Its existence may be demonstrated in any muscular fibre, by subjecting it to the action of fluids, which occasion a swelling of its contents; this is especially the effect of acids and alkalies, and may be well produced by the citric and tartaric acids, and by potash. For a time, the Sarcolemma yields to the distension which takes place from within; but at last it bursts at particular points, and a sort of hernia of its contents takes place, making the existence of a perfect envelope in all other parts quite evident. This membrane is itself perfectly transparent, and has nothing to do with the production of either the longitudinal or the transverse striæ. There is no reason to believe that it is perforated either by nerves or by capillary vessels; in fact it seems to be an effectual barrier between the real elements of Muscular structure, and the surrounding parts. That it has no share in the contraction of the fibre, is evident from the fact just mentioned, respecting the condition which it occasionally presents when the fibre is much shortened.

Fig 27.

Fibre of Human muscle broken across: the fragments connected by the untorn sarcolemma.

368. Muscular Fibres are commonly described as cylindrical; but there is reason to believe that they are rather of a polygonal form, their sides being flattened against those of adjoining fibres. In some instances the angles are sharp and decided; in others they are rounded off, so as to leave spaces between the contiguous fibres for the passage of vessels. In Insects, the fibres often present the form of flattened bands. Their size varies considerably in different classes of animals; and even in the same animal, and the same muscle. The following table gives illustrations of these varieties; the extremes are those met with by Mr. Bowman himself; but other observers speak of dimensions more widely separated.

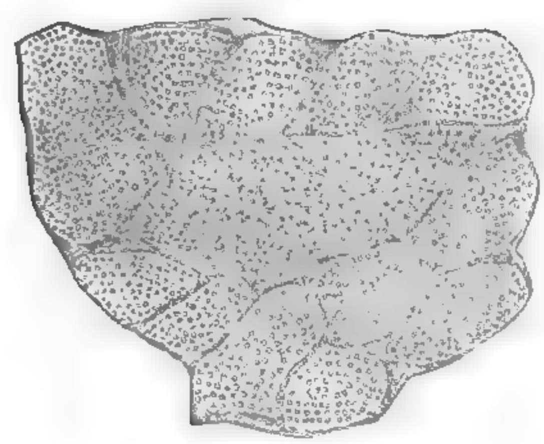
			Fractions of an inch.
MAMMALIA	Human	Male	[illegible] to [illegible]
		Female	[illegible] to [illegible]
	Cat		[illegible] to [illegible]
	Horse		[illegible] to [illegible]
	Mole		[illegible] to [illegible]
	Mouse		[illegible]

* See Bowman on the Minute Structure and movements of Voluntary Muscle in Phil. Trans. 1840. His description is here followed by the Author, as that most conformable to his own observations.

		Fractions of an inch.
Birds	Owl	$\frac{1}{1000}$ to $\frac{1}{300}$
	Chaffinch	$\frac{1}{300}$ to $\frac{1}{700}$
	Heron	$\frac{1}{1500}$ to $\frac{1}{316}$
Reptiles	Frog	$\frac{1}{1000}$ to $\frac{1}{100}$
	Lizard	$\frac{1}{600}$
	Boa	$\frac{1}{600}$ to $\frac{1}{150}$
Fish	Skate	$\frac{1}{300}$ to $\frac{1}{65}$
	Cod	$\frac{1}{222}$ to $\frac{1}{60}$
	Sprat	$\frac{1}{600}$ to $\frac{1}{300}$
Insects	Staghorn Beetle	$\frac{1}{435}$ to $\frac{1}{310}$
	Blue-bottle Fly	$\frac{1}{725}$ to $\frac{1}{400}$

It is interesting to remark, upon this table, that the Muscular Fibre of Reptiles and Fishes is upon the whole much larger than that of other Vertebrata, and that its dimensions present the greatest extremes of variation; whilst in Birds, it is much smaller than in all other Vertebrata, and its dimensions are also less variable. Further, the size of the fibres bears no proportion to that of the animal; for we observe that in the Chaffinch they are larger than in the Owl, in the Cat larger than in the Horse, and in the Frog often larger than in the Boa. Moreover in Insects, the diameter of the fibres is even greater than it is in Mammalia. Some difference of opinion exists as to whether the arrangement of the fibrillæ within the sarcolemma is such as to form a hollow or solid bundle. It frequently happens that, when a fibre is torn across, the appearance of the brush-like tuft of fibrillæ at the broken extremity is such, as to indicate that they form a hollow cylinder; but this may be accounted for by the fact, that the outer layer of fibrillæ is evidently adherent in some degree to the Sarcolemma, and will consequently be extended with it, at the moment of its rupture, beyond the deeper layers. The appearance presented by transverse sections shows that the bundle of fibrillæ contains no central cavity; the extremities of the cut fibrillæ, however, cannot always be distinguished in Mammalia, in consequence, as it would seem, of their close and intimate lateral union; but they are very evident in Birds, Reptiles, and Fishes (Fig. 28). The addition of

Fig. 28.



Transverse section of Muscular fibres from pectoral muscle of Teal; showing the irregular form of the fibre and the cut extremities of the fibrillæ, with which they are completely filled.

an acid increases the distinctness of the fibrillæ, by widening the interstices between them.

369. When the fibrillæ are separately examined, they are found to present an alternation of dark and light spaces; and these points are capable of being reversed, by an alteration of the focus of the microscope, so that the appearance is evidently due to the mode in which the light passing through them is refracted, and not to any difference of colour in the two series of points. It is in fact precisely that which is given by a glass rod with beaded enlargements, when held to the light; the beads will appear bright, and the intervening spaces dark. Considerable variety exists in different animals, as to the relative proportions of these two parts. According to Schwann (who regards the dark points as enlargements, and the light as the narrow connecting part), the dark portion, in a fibre from the Human pharynx, was about one-third, and the light portion two-thirds, of the whole space occupied by each segment of the fibril. In the Hare, as figured by Mr. Bowman, the light and dark portions are nearly equal. In some instances, the beads appear close together, and their long diameter is transverse to the direction of the fibril; whilst in the ocular muscle of the Fish, the beads seem to have somewhat of a lozenge form, overlapping each other without any intervals. The relative proportion between the diameter of the beads, and the interspaces between them, will depend in part upon the condition of the muscle at the time it is examined; for if in a state of contraction, the beads will probably be much more closely approximated than when the muscle is relaxed. This appears from what is next to be stated of the nature of the transverse striæ exhibited by the fibre, and of the changes which they undergo during the action of the muscle. The size of the ultimate fibrils is stated by Wagner to be nearly the same in all Vertebrata, as well as in Insects, and in the Craw-fish; its usual extremes being from about $\frac{1}{8500}$ to $\frac{1}{11074}$ of an inch: but Muller has observed them in the Frog to be sometimes as much as $\frac{1}{5538}$ of an inch, and in the Parrot to be $\frac{1}{4330}$ of an inch in diameter. Taking the average stated by Wagner, and comparing it with the average dimensions of the fibre in the Human Species, which is estimated by Mr. Bowman at about $\frac{1}{400}$ of an inch, each Muscular fibre in Man may be regarded as composed of from five to eight hundred fibrillæ.

370. The Muscular Fibre of Animal life is peculiarly characterized by the existence and close arrangement of alternate light and dark lines, crossing it transversely. By several observers, these have been supposed to be due to the pressure of circular bands or girths, surrounding the fibrillæ; and some have even imagined that they might be attributed to a continuous spiral coil. The existence of such bands is not, however, indicated in any other way. As already stated, the fibrillæ are only bound together by the Sarcolemma or enveloping tube; and this is composed of a simple transparent membrane, destitute of any appearance of bands. The spaces between the light and dark striæ on the fibre exactly correspond with those between the light and dark points in individual fibrillæ; and this is the case in all conditions of the muscle; so that it cannot be doubted that the appearance must be the result of the same cause in each condition. By Mr. Skey it has been imagined that the circular bands, which he supposed to cause the striæ, made little indentations in the fibrillæ; but it is obvious that these indentations would not extend to those in the interior of the bundle, which, though supposed by Mr. Skey to be hollow, has been clearly proved by Mr. Bowman to be solid, and to contain beaded fibrils in its centre as well as near its exterior. There can be little doubt, then, that the transverse striæ are the result of the collocation of the beaded fibres, in such a manner

that their dark and light spaces shall correspond, as shown in the adjoining figure. These striæ can be seen, not only on the exterior of the fibre, but in every part of its thickness; since, owing to the transparency of the whole, it is easy to bring any portion of the interior into focus. The *average* distance of the striæ in the muscular fibre of different animals, is very nearly uniform; as will be seen from the following table. Between the extremes, however, there is considerable variation; and this presently will be shown to depend upon the condition of the muscle at the time of examination. The distance is not only often different in the same muscle and the same fasciculus, but even in the same fibre in different parts of its length. The figures indicate the number of striæ in $\frac{1}{1000}$ of an inch.

Fig. 29.

Fragment of Muscular fibre from macerated heart of Ox, showing formation of striæ by aggregation of beaded fibrillæ. After Bowman.

	Maximum.	Minimum.	Mean.
Human	15·0	6·0	9·4
Other Mammalia	15·0	6·7	10·9
Birds	14·0	7·0	10·4
Reptiles	20·0	6·7	11·5
Fish	18·0	7·5	11·1
Insects	16·0	4·5	9·5

The extremes *in the same specimen*, however, were in no instance so widely apart as the table indicates for the Class; the greatest proportion between the Maximum and Minimum being, except in Insects, as 2 to 1. The beaded enlargements of the different fibrillæ appear to have a close adhesion to each other; so that we may consider the fibre as not only made up of longitudinal filaments, but of disks formed by the lateral adhesion of the beads, and connected together by their intervening narrow bands. When the two ends of a fibre are drawn apart, it will not unfrequently happen that there is a greater tendency to a transverse separation between the disks, than there is to a longitudinal splitting of the fibrillæ. In fact we must consider the primitive component segments of the fibrillæ as the ultimate elements of the fibre; these segments being connected longitudinally, so as to constitute the fibrillæ, the distinctness of which is marked, even in the complete fibre, by longitudinal striæ; whilst they also adhere laterally, so as to form disks, the partial separation of which gives

Fig. 30.

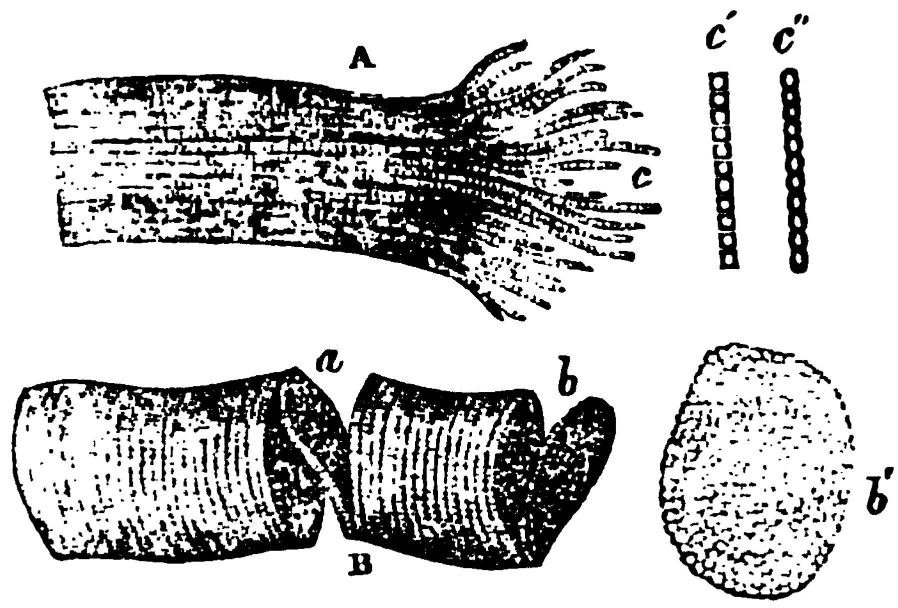
Portion of Human Muscular fibre, separating into disks, by cleavage in direction of transverse striæ. After Bowman.

origin to the transverse striæ. The reason why the transverse striæ are ordinarily so much darker than the longitudinal, is that the fibrillæ are closer together than the disks, and their shaded interspaces consequently narrower.

{ Mr. Bowman, in a recent work, thus speaks of the internal structure and *cleavage* of muscles:—

"The beautiful cross-markings on the voluntary fibre have been known from the early days of microscopical research, and have given occasion to a variety of hypothetical and generally mechanical solutions of the problem of contraction; which, by warping the minds of observers, have had the effect of greatly complicating an already difficult subject, that of the internal anatomy of the fibre, which can only be determined by pure observation. Fontana alone among the older anatomists abstained from vague speculation; and he arrived nearest to the truth. He found that the fibre was apt to split up into fine fibrillæ, each of which was a series of particles; and he imagined that the transverse lines were caused by the regular apposition side by side of the particles of the contiguous fibrillæ. It was customary both before and since his time, as at the present day, to regard the fibre as a bundle of smaller ones, whence the term *primitive fasciculus*, first given to it by him and adopted by Müller: but this view of the subject is imperfect. The fibre always presents, upon and within it, longitudinal dark lines, along which it will generally split up into fibrillæ; but it is by a fracture alone that such fibrillæ are obtained. They do not exist as such in the fibre. And, further, it occasionally happens that no disposition whatever is shown to this longitudinal cleavage; but that, on the contrary, violence causes a separation along the transverse dark lines, which always intersect the fibre in a plane perpendicular to its axis. By such a cleavage, discs, and not fibrillæ, are obtained; and this cleavage is just as natural,

Fig. 30*.



Fragments of striped elementary fibres, showing a cleavage in opposite directions; magnified 300 diameters:—A. Longitudinal cleavage. The longitudinal and transverse lines are both seen. Some longitudinal lines are darker and wider than the rest, and are not continuous from end to end: this results from partial separation of the fibrillæ. *c*. Fibrillæ, separated from one another by violence at the broken end of the fibre, and marked by transverse lines equal in width to those on the fibre. *c′*. *c″*. represent two appearances commonly presented by the separated single fibrillæ. (More highly magnified.) At *c′*. the borders and transverse lines are all perfectly rectilinear, and the included spaces perfectly rectangular. At *c″*, the borders are scalloped, the spaces bead-like. When most distinct and definite, the fibrilla presents the former of these appearances.—B. Transverse cleavage. The longitudinal lines are scarcely visible. *a*. Incomplete fracture following the opposite surfaces of a disc, which stretches across the interval and retains the two fragments in connection. The edge and surface of this disc are seen to be minutely granular, the granules corresponding in size to the thickness of the disc, and to the distance between the faint longitudinal lines. *b*. Another disc nearly detached. *b′*. Detached disc more highly magnified, showing the sarcous elements.

though less frequent than the former. Hence it is as proper to say that the fibre is a pile of discs, as that it is a bundle of fibrillæ: but, in fact, it is neither the one nor the other, but a mass in whose structure there is an intimation of the existence of both, and a tendency to cleave in the two directions. If there were a general disintegration along all the lines in both directions, there would result a series of particles, which may be termed *primitive particles* or *sarcous elements*, the union of which constitutes the mass of the fibre. These elementaay particles are arranged and united together in the two directions. All the resulting discs as well as fibrillæ are equal to one another in size, and contain an equal number of particles. The same particles compose both. To detach an entire fibrilla is to abstract a particle of every disc, and *vice versâ*. The width of the fibre is therefore uniform, and is equal to the diameter of any one of the discs. Its length is the length of any one of its fibrillæ, and is liable to the greatest variety." M. C.}

371. The general opinion as to the disposition of the fibres during the contraction of muscle, has been that of Prevost and Dumas, who stated that they are thrown into a sinuous or zig-zag flexure. Recent observations, however, have fully demonstrated the incorrectness of this view; the improbability of which might have been suspected from the consideration, that fibres in this state of flexure could not be imagined to be exerting any force.* Prof. Owen has noticed that, in the contracted state of the very transparent muscles of some Entozoa, each separate fibre, which may be seen with great distinctness, presents a knot or swelling in the middle, besides being generally thickened; but that it is simply shortened, without falling out of the straight line. Dr. A. Thomson remarked the same thing in the Frog; single fibres, whilst continuing in contraction, being simply shortened, without falling into zig-zag lines: and he was led to suspect, from this and other circumstances, that the zig-zag arrangement was not produced until the act of contraction had ceased. The recent inquiries of Mr. Bowman appear to have proved most satisfactorily, that, in the state of contraction, there is an approximation of the transverse striæ, and a general shortening of the fibre; and that its diameter is at the same time increased; but that it is never thrown out of the straight line, except when it has ceased to contract, and its two extremities are still held in proximity by the contraction of other fibres. The whole process may be distinctly seen under the Microscope in a single fibre isolated from the rest; it is, of course, desirable to select from those animals in which the contractility of the Muscle is retained for the longest period after death, which is particularly the case in Reptiles among Vertebrata, and in most Invertebrata (Mr. Bowman particularly recommends the Crab and Lobster); but it has been fully proved to differ in no essential degree in the warm-blooded Vertebrata. The contraction usually commences at the extremities of the fibre; but it frequently occurs also at one or more intermediate points. The first appearance is a spot more opaque than the rest, caused by the approximation of a few of the segments of some of the fibrillæ; this spot usually extends in a short time through the whole diameter of the fibre, and the shading, caused by the approximation of the transverse striæ, increases in intensity. The striæ

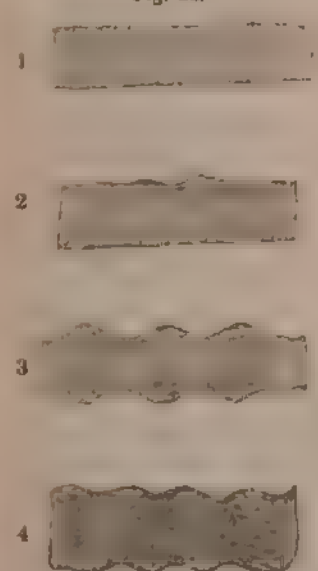
* By Prevost and Dumas themselves it was imagined, that the muscular fibres themselves were passive agents in contraction; and that the real power was given by an attractive force, analogous to or identical with that of electricity, existing between the nervous fibres, which were stated by them to be disposed in parallel rows, transversely to the direction of the muscle. Other Physiologists, however, have shown that this was a hasty assumption.

are found to be two, three, or even four times as numerous in the contracted, as in the uncontracted part, and are also proportionally narrower and more delicate. The line of demarcation between the contracted and uncontracted portions is well defined; but, as the process goes on, fresh striæ are absorbed (as it were) from the latter into the former. The contracted part augments

Fig. 31.

Muscular fibre of Dytiscus, contracted in the centre, the striæ approximated; the breadth of the fibre increased, and the sarcolemma raised in bullæ on its surface. After Bowman.

Fig. 32.



Muscular fibre of Skate, in a state of rest (1), and in three different stages of contraction (2, 3, 4). After Bowman.

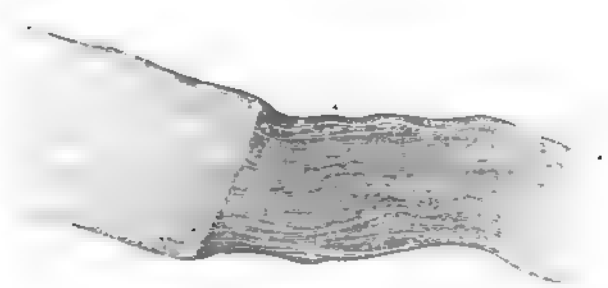
in thickness; but not in a degree commensurate with its diminished length; so that its solid parts lie in smaller compass than before, the fluid which previously intervened between them being pressed out in bullæ under the sarcolemma (Fig. 31). The force with which the elements of the fibre thus tend to approximate is evidently considerable; for if the two extremities be held apart, the fibre is not unfrequently ruptured. This corresponds with the appearances found in the muscles of persons who have died from tetanus; for in the ruptured fibres of those muscles which had been the subjects of the spasmodic action, the striæ have been observed to approximate so closely as to be scarcely distinguishable. When the contraction is not very decided, the dark and elevated spot appears to play like a wave along the fibre, before it involves the whole diameter in any part; and even when considerable traction is being exercised, there is continual interchange in the elements by which it is effected,—the discs at one end of the contracted part receding from each other, whilst at the other end new discs are being received into it.

372. The foregoing description is chiefly derived from the appearances presented by muscular fibre, when spontaneously passing into that state of contraction, which is termed the *rigor mortis;* and it has not been fully demonstrated that the phenomena of contraction excited by the agency of the nerves, are precisely similar. Mr. Bowman has remarked, however, that stimuli of various kinds, directly applied to them, produce corresponding effects, although, in the case of galvanism, the change is too rapid for its steps to be followed; and that, from the appearances presented by muscles that have been affected with tetanic spasms, the contraction produced by nervous agency does not essentially differ in character. It now remains

therefore, to inquire, what is the cause of the zig-zag arrangement, which is often seen in the fibres. This may be easily produced, by approximating the ends of a fasciculus, after the irritability of its fibres has ceased; and it would not seem unlikely that the passage of vessels or nerves should determine the points at which the flexures take place. Hence it appears, that the sinuous or zig-zag arrangement is that into which fibres are naturally thrown, if, on elongation following contraction, they are not at once stretched by antagonist muscles. Many facts support the opinion, which has long been held by several physiologists, that, when an entire muscle is contracting, all its fasciculi are not in contraction at once; but that there is a continual interchange in the parts by which the tension is effected; some relaxing, whilst others are shortening. When the ear is applied to a muscle in vigorous action, an exceeding rapid faint silvery vibration is heard; which seems to be attributable to this constant movement in its substance. Now, on examining a muscle, of which some fasciculi present the zig-zag arrangement, others will be seen (if the two extremities have not been purposely approximated) to be quite straight, and in a state of contraction; and it thence appears that the former appearance is presented by bundles of fibres which have either not yet entered into contraction, or have relaxed after undergoing it, but of which the extremities are still approximated by the agency of other contracting fibres. From the fact, that a single muscular fibre, isolated from all other tissues, can pass into a state of complete contraction, when subjected to excitement of some kind, the very important inference may be drawn,—that the property of contractility is inherent in the tissue itself, and is not dependent (as some Physiologists have supposed) upon nervous agency, though usually called into action by it in the living body. This inference will be shown to be fully borne out by physiological facts. The result of various experiments made for the purpose, leads to the conclusion that the total bulk of a muscle in contraction is not less than when it is in a relaxed state; or that the difference, if any exist, is extremely trifling.

373. All muscular fibres are attached at their extremities to tissues of the ordinary fibrous character, and most commonly to that which is known as *tendinous* structure. The component fibres of this are arranged, with great regularity, parallel to each other; and they are attached to the end of the sarcolemma, which terminates abruptly, so that the muscular fibre does not taper to a point as some have supposed. The line of demarcation between the muscular and tendinous structure is always very distinct.

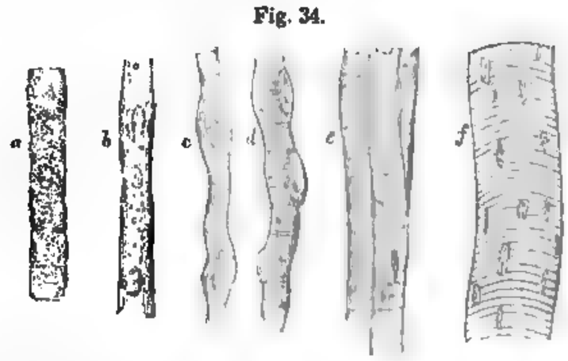
Fig. 33.



Attachment of Tendon to Muscular fibre, in Skate. After Bowman.

374. The Sarcolemma of the Muscle, like the tube of the Nerve (§110), appears to be the part first formed, being distinctly visible long before any traces of fibrillæ can be observed in it. This tube takes its origin, like the ducts of Plants, in cells laid end to end, the partitions between which are broken down at a subsequent period; and the nuclei of these original cells may be distinctly seen for some time after the appearance of the striæ, which indicate the formation of the fibrillæ in their interior. In an early stage of the development of the fibres, indeed, these bodies project considerably from their sides; in this respect, as well as in others, there is a close correspondence between the *temporary* character of the Muscular fibre of Animal life, and the *permanent* condition of that of Organic life. In the fully-formed muscle of Animal life, they are not perceptible, except when a peculiar method has been adopted for bringing them into view. This method consists in treating the fibre with acids, which renders them more opaque, whilst the surrounding structure becomes more transparent. They are usually numerous in proportion to the size of the fibre; when the fibre is small, as in Birds or Mammalia, they lie at or near its surface; but in those of greater bulk, as in Fishes and Reptiles, they are intermingled with the fibrillæ through the whole thickness of the fibre, and are brought into view by a transverse section. It would seem probable that these bodies are continually exercising their function,—that of giving origin to new cells, and thence to new muscular tissue; since their amount is far greater in the adult than in the fœtus, their number relatively to the bulk of the fasciculi (which is in the fœtus about one-third of that of the adult) being nearly the same at the two periods. In the Larvæ of several Insects, perfect and imperfect fibres may often be found lying side by side.

Fig. 34.



Stages of the development of striped muscular fibre.
a. Arrangement of the primitive cells in a linear series.—After Schwann.
b. The cells united. The nuclei separated, and some broken up; longitudinal lines becoming apparent.—From a fœtal calf three inches long.
c. d. Transverse stripes apparent. In *c*, the nuclei are internal, and bulge the fibre. In *d*, they are prominent on the surface.—From a fœtal calf of two months old.
e. Transverse stripes, fully formed and dark, nuclei disappearing from view.—From the human infant at birth.
f. Elementary fibre from the adult, treated with acid, showing the nuclei.—Magnified about 300 diam. After Bowman.

Muscles of Organic Life.

375. The Muscular fibre of Organic life is very different from that which has been thus fully described. It consists of a series of tubes which do not present transverse striæ, and in which the longitudinal striæ are very faint

these tubes are usually much flattened, and cannot be shown to contain distinct fibrillæ. Their size is usually much less than that of the fibres of Animal life; but, owing to the extreme variation in the flattening which they undergo, it is difficult to make a precise estimate of their dimensions. Those of the alimentary canal of Man are stated by Dr. Baly to measure from about $\frac{1}{2500}$ to $\frac{1}{3600}$ part of an inch. In all instances, the nuclei of the cells in which they originate are very perceptible; and from their similarity to the imperfectly-formed *fibres* of Animal life, it would seem that they are rather to be compared with these than with their *fibrillæ*, to which some have considered them analogous. These fibres are, like those of the other muscles, arranged in a parallel manner into bands or fasciculi; but these fasciculi are generally interwoven into a network, not having any fixed points of attachment, but contracting against each other. This kind of structure is that which forms the muscular coat of the œsophagus, stomach, intestinal tube, bladder, pregnant uterus, and trachea; and perhaps, also, that of the iris. The pharyngeal muscles, however, belong to the former system. The distinctness between the two is remarkably shown in bodies infested with the Trichina spiralis, which, whilst it profusely infests the former, is seldom or never found in the latter; so that there is a definite line of demarcation, even in closely contiguous parts, such as at the lower edge of the inferior constrictor of the pharynx. The fibres of the uterus somewhat differ in aspect from those of other parts; being much broader at their centre, and tapering off at their extremities into what appear to be cylindrical parts. In the heart, according to Mr. Skey, both the Animal and Organic muscular fibres are found; and this accords with the structure of the organ, which affords some fixed points, whilst much of its action resembles (except in its greater degree of vigour) that of the muscular coat of the intestines. It is a curious and interesting fact, that in Articulata, whose *animal* life is so predominant (§ 22), the Animal muscular fibre is formed as perfectly as in the highest Vertebrata; whilst in Mollusca, whose character is exactly the reverse (§ 28), no striated fibres can be detected.

Properties of Muscular Fibre.

376. Muscles may be thrown into contraction, so long as they preserve their vitality, by stimuli applied to themselves. Mechanical and chemical influences, cold, heat, and electricity, produce this effect. They do not lose their vitality immediately on the general death of the system, which must be considered as taking place when the circulation ceases without a power of renewal; in cold-blooded animals it is retained much longer after this period, than in the higher Vertebrata, in some of which it disappears within an hour. From experiments on the bodies of executed criminals who were previously in good health, Nysten ascertained that in the Human subject, the irritability departs in the following time and order.—The left ventricle of the heart first; the intestinal canal at the end of 45 or 55 minutes; the urinary bladder nearly at the same time; the right ventricle after the lapse of an hour; the œsophagus at the expiration of an hour and a half; the iris a quarter of an hour later; the muscles of Animal life somewhat later; and lastly, the auricles of the heart, especially the right, which in one instance contracted under the influence of galvanism 16½ hours after death. The muscles of young animals generally retain their contractility for a longer time than those of adults; on the other hand, those of Birds lose their irritability sooner than those of Mammalia. Hence, as a general rule, the duration of the irritability is inversely to the amount of respiration. Muscular

contractility is deadened by many substances, especially by those which have a narcotic or sedative action on the nervous system. In carbonic acid gas, hydrogen, carbonic oxide, or sulphurous acid gas, muscles contract very feebly or not at all when stimulated; whilst in oxygen they retain their contractility longer than usual. Narcotic substances, such as a watery solution of opium, when applied directly to the muscles, have an immediate and powerful effect in diminishing or even destroying their contractility; this effect is also produced, though in a less powerful degree, by injecting these substances into the blood. In the same manner, venous blood, charged with carbonic acid, and deficient in oxygen, has the effect of a poison upon muscles, diminishing their irritability, when it continues to circulate through them, to such a degree, that they sometimes lose it almost as soon as the circulation ceases, as is seen in those who have died from gradual and therefore prolonged Asphyxia. The unfavourable influence of venous blood is also shown in the Morbus Cœruleus; patients affected with which are incapable of any considerable muscular exertion. Most of the stimuli which occasion muscular contraction, when directly applied to their fibres, operate also when applied to their motor nerves; but the same does not hold good in regard to those agents which diminish contractility. It is a fact of some importance, in relation to the disputed question of the connection of muscular irritability with the nervous system, that when, by the application of narcotic substances to the nerves, their vital properties are destroyed, the irritability of the muscle may remain for some time longer; and the latter must, therefore, be independent of the former. Hence we should conclude that contractility must be a property really inherent in Muscular tissue, which may be called into action by various stimuli applied to itself, and which may be weakened by various depressing agents applied to itself; and that the nerves have the power of conveying the stimuli which call the property into action, but have little or no other influence on it.

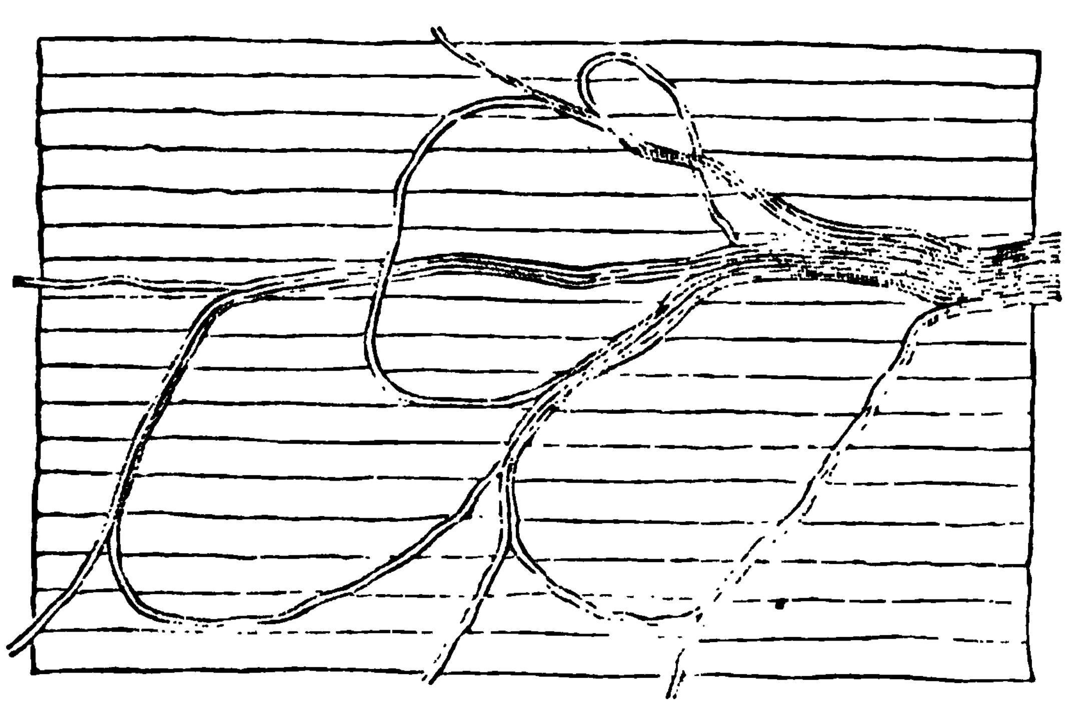
377. It seems to be a general law of Muscular Contraction, that it shall alternate with relaxation at no long intervals. This is most evident in the action of the Heart, and in the peristaltic movements of the Alimentary canal. In these parts, the whole or a large part of the fibres seem to contract together, and then shortly to relax; but it is probably no less true, as has been just shown, of the individual fibres of the muscles which are kept in a state of contraction by an effort of the will, since none of them appear to remain in a contracted state for any length of time. The peculiar contractility of Muscular tissue, like the vital properties of other parts, is diminished by want of action; and in this, as in other cases, it is quite clear that the cause of its loss is to be found in the alteration of the nutritive processes, which results from the cessation of the usual operations of the part (§ 221). In persons whose lower extremities have, from any cause, been long disused, not only does the bulk of the muscles greatly diminish, but their characteristic structure in great part disappears, degenerating into fat mixed with ordinary fibrous tissue. On the other hand, a frequently-renewed exercise of muscular contractility increases the power, by stimulating the increased nutrition of the muscles, which become more developed, and consequently more powerful; this is well seen in the arms of the Smith or Waterman, and in the legs of the Opera-dancer. But the exercise must not be too constant; for it appears to be during the intervals of rest, that the increased nutrition chiefly takes place; and if the action be of a violent character, the contractility of the muscle is for a time exhausted, and can only be restored by an interval of inactivity. There is no foundation, however, for the belief, which has been entertained by some

physiologists, that the irritability of a muscle may accumulate during a state of inaction; the fact being, as just stated, that prolonged inactivity diminishes the vital energy of the part. The experiments which appear to favour such a doctrine are to be explained in other ways; thus, when Heat is employed as a stimulus, after the continuance for a short time of cold, an unusual effect takes place, which is evidently to be ascribed to the greater amount of *change* of temperature involved in its application,—the degree of change, rather than the absolute elevation, being that which determines the force of the stimulus.

378. The effects of stimuli locally applied to portions of the Muscles of Animal life are very different from those which result from their application to the muscles of Organic life. If, for example, we irritate mechanically a portion of the Biceps, the fasciculus of fibres which is touched will contract, but the surrounding parts will be unaffected, and the contracted fasciculus soon relaxes; in fact, the only way to call the whole muscle into contraction at once is to stimulate it through its nerves. On the other hand, if we apply a similar irritation to the intestinal canal, when in a state of equal contractility, the fasiculus which is stimulated shortens in a much greater degree, and propagates its action in a wave-like manner to other bundles of fibres, so that successive contractions and relaxations may be produced through a considerable part of the canal by a single prick with the point of a scalpel: but the contractions into which these same fibres are thrown by irritating their nerves are for the most part feeble and undecided (§ 200). It is, indeed, a curious fact, corroborative of what has been just said of the influence of narcotics, that the ganglionic nerves much sooner lose their power of exciting these muscles to contraction when themselves irritated, than the muscles lose their power of contracting when directly stimulated.

379. There can be no doubt that it is through the motor or efferent nerves, that contraction is ordinarily excited in the muscles of the first class, in the living body; and these nerves may, as formerly shown, convey the influence of volition, of emotional or instinctive operations of mind, or of the reflex action of the Spinal Cord. As the effect produced upon the muscle is in all instances similar, there can be little doubt that the stimulus actually communicated by the nerve is the same. The motor nerves cannot be properly said to *terminate* in the muscles; for the trunks form a

Fig. 35.



Form of the terminating loops of the nerves in the muscles. After Burdach.

kind of network in their substance, the fibres which they send off returning again to themselves, by loops, or to other trunks. In what manner the stimulus is conveyed and communicated can only be at present a matter of speculation; that the influence is of an electrical kind has been supposed by some, principally on account of the similarity between muscular contractions excited by galvanism transmitted through the nerves, and those ordinarily produced by voluntary direction. But it is to be remembered that other agents, both physical and chemical, may produce the same effect; and there are objections, which at present appear insuperable, to the belief that nervous influence and electricity are *identical*, whatever may be the analogy in their mode of operation. The muscles of the second class appear to be, in the living body, much seldomer called into contraction through their nerves, than they are by stimuli applied directly to themselves. The will has no power over them; and they would seem to be rather affected by those emotional conditions of mind, which volition cannot imitate. This influence is continually experienced in the action of the heart, and probably also affects the movements of the intestinal tube.

380. The continual and evident influence of the Nervous System upon Muscular contractility, has led many physiologists to the belief, that the latter is *dependent* upon the agency of the former. Two views upon this question have been commonly taught, to both of which it seems necessary to devote a brief consideration. The first of these is, that Muscular Irritability is derived from some influence or energy communicated from the Brain or Spinal Cord. This opinion is evidently analogous to that which attributes the vital properties of other parts to the Nervous System alone; and it is open to the same objection, *in limine*, which has been applied to the latter,—the improbability that any one of the solid textures of the living body, should have for its office to give to any other the power of taking on any vital action. Moreover it is inconsistent with the fact that, in Vegetables, tissues endowed with a high degree of contractility exist, and manifest their property when a stimulus is directly applied to themselves, which, nevertheless, can have no dependence whatever upon a nervous system; and in the lower classes of Animals there is good reason to believe, that the property is much more universally diffused through their tissues, than nervous agency can be. Again, the action of the heart may be kept up, in the highest animals, by taking care that the current of the circulation be not interrupted, for a long time after the removal of the brain and spinal cord; it may even continue when completely separated from the body, which shows that the ganglionic system cannot supply any influence necessary to it; and there are many instances in which the human fœtus has come to its full size, so that its heart must have regularly acted, without the existence of a brain or spinal cord. Further, the irritability of muscles of the first class continues for a long time after their nerves are divided, and may be called into action by stimuli directly applied to the parts themselves, or to their nerves below the section, so long as their nutrition is unimpaired.

381. The loss of the irritability of muscles, within a few weeks after the section of their nerves, on which great stress has been laid by Müller in support of a modified form of the above doctrine, (it being maintained by this distinguished physiologist, that, if muscular irritability is not *dependent* on the Brain and Spinal Cord, they supply some influence essential to its exercise,) is clearly due to the alteration in their nutrition consequent upon their disuse. This has been recently proved to demonstration, by

the very ingenious experiments of Dr. J. Reid.* "The spinal nerves were cut across, as they lie in the lower part of the spinal canal, in four frogs; and both posterior extremities were thus insulated from their nervous connections with the spinal cord. The muscles of one of the paralyzed limbs were daily exercised by a weak galvanic battery; while those of the other limb were allowed to remain quiescent. This was continued for two months; and at the end of that time, the muscles of the exercised limb retained their original size and firmness and contracted vigorously, while those of the quiescent limb had shrunk to at least one-half of their former bulk, and presented a marked contrast with those of the exercised limb. The muscles of the quiescent limb still retained their contractility, even at the end of two months; but there can be little doubt that, from their imperfect nutrition, and the progressing changes in their physical structure, this would in no long time have disappeared, had circumstances permitted the prolongation of the experiment." This experiment satisfactorily explains the fact observed by Dr. M. Hall, and heretofore adverted to (§ 208), that, in cases in which the cause of the paralysis is situated in the Brain, and the Spinal Cord and its nerves are unaffected, the irritability of the muscles of the paralyzed part is not destroyed, even after a considerable lapse of time. For, if the capability of performing reflex actions still exist on the part of the nervous system, it is manifest that the muscles will be continually excited to action through this channel, and that their nutrition and vital properties will thereby be preserved, as they were in Dr. Reid's experiments by the artificial excitement of galvanism. Hence Dr. M. Hall's opinion, that the property of Muscular Contractility is derived from the Spinal Cord, is no more tenable than that which locates it in the Brain.

382. The loss of contractility from section of the nerves takes place more speedily in warm-blooded Vertebrata, all whose vital operations are performed with a much greater activity, than in Reptiles and other cold-blooded animals. Dr. Reid found that, in a Rabbit, a portion of whose sciatic nerve had been removed on one side, the muscles of that leg were but very feebly excited to contraction by Galvanism, after the lapse of seven weeks. The change in their nutrition was evident to the eye, and was made equally apparent by the balance. The muscles of the paralyzed limb were much smaller, paler, and softer, than the corresponding muscles of the opposite leg; and they scarcely weighed more than half, being only 170 grains, whilst the others were 327 grains. It was found, also, that a perceptible difference existed in the size of the bones of the leg, even after so short an interval had elapsed; the tibia and fibula of the paralyzed limb weighing only 81 grains, whilst those of the sound limb weighed 89 grains. On examining the muscular fibres with a microscope, it was found that those of the paralyzed leg were considerably smaller than those of the sound limb, and presented a somewhat shrivelled appearance; and that the longitudinal and transverse striæ were much less distinct.

383. Another equally satisfactory proof, that the loss of Contractility, which follows the severance of the connection between the Nervous centres and the Muscle, is not immediately due to the interruption of any influence communicated by the former, has been given by the experiments of Dr. J. Reid. It was asserted by Mr. Earle (and the statement has been repeated by Müller) that, if the irritability of a muscle, whose nerves have been divided, be exhausted by repeated stimulation, it cannot be recovered. Dr. J. Reid has shown, however, that the means employed by Mr. E. to

* Edinburgh Monthly Journal of Medical Science, May, 1841.

exhaust the irritability were such, as would probably induce an inflammatory condition of the muscle, and would thereby interfere with the nutritive processes which would be necessary to reestablish the irritability during the state of subsequent quiescence. And he has further proved, that if the contractility be exhausted by means which have no such unfavourable tendency, and the other conditions favour the normal performance of the nutrient processes, the irritability *is* restored, and remains for some time. His first experiments were on cold-blooded animals, and they would in themselves be sufficiently satisfactory; but he has since repeated them in the Rabbit, and established the fact beyond all doubt. "The sciatic nerve was divided in the Rabbit, and a portion of it removed. One wire from two galvanic batteries consisting of thirty pairs of plates, was applied over the course of the nerve; and the other wire was applied over the foot, which was kept moist, until the muscles had ceased to contract. Three days after this a weaker battery was used, and the muscles of the limb had recovered their contractility, and contracted powerfully. The more powerful battery was used as before, until the muscles had ceased to respond to the excitement; and three days after this, they had again recovered their contractility." It seems scarcely possible to draw any other inference from these experiments, than that Contractility is a property inherent in Muscular tissue, and that the agency of the Nervous system upon it is merely to call it into active operation.

384. The second doctrine above referred to (§ 380) as having been taught by some Physiologists, is that Muscles, though not dependent on nerves for vital power, are yet dependent upon them for the exercise of that power,—all stimuli, which excite muscles to contraction, operating first on the nervous filaments which enter muscles, and through them on the muscular fibres. The facts which have been already stated in regard to the ordinary action of the Muscles of Organic life, furnish a sufficient answer to this hypothesis. It is with great difficulty that these can be made to display their irritability by any stimuli applied to their nerves; whilst they manifest it strongly, when the stimulus is directly applied to themselves. Even in the Muscles of Animal life, individual fasciculi may be thrown into action in the same manner, although the entire mass cannot be put into combined operation, except by a stimulus simultaneously communicated to the whole, which the nerve affords the readiest means of effecting. Perhaps the most satisfactory disproof of it, however, is to be found in the observation of Mr. Bowman already cited (§ 371), that a single fibre, completely isolated from all its connections, may be seen with the microscope to pass into a state of contraction, under the influence of direct irritation. Further, it has been experimentally ascertained that there are some chemical stimuli, which will produce the contraction of muscles when directly applied to them, but of which the influence cannot be transmitted through the nerves; this is especially the case with regard to acids.

385. When all these considerations are allowed their due weight, we can scarcely do otherwise than acquiesce fully in the doctrine of Haller, which involves no hypothesis, and which is perfectly conformable to the analogy of other departments of Physiology. He regarded every part of the body which is endowed with irritability, as possessing that property in and by itself; but considered that the property is subjected to excitement and control from the Nervous System, the agency of which is one of the stimuli that can call it into operation. It may be desirable to recapitulate briefly the facts by which this doctrine is supported. 1. The existence in Vegetables of irritable tissues, which are excited to contraction by stimuli directly ap-

plied to themselves, and can be in no way dependent upon, or influenced by, a nervous system. 2. The existence in Animals of a form of Muscular tissue, which is especially connected with the maintenance of the Organic functions, and which is much more readily excited to action by direct stimulation, than it is by nervous agency. 3. The fact that, by the agency of these, the organic functions may go on (as long as their other requisite conditions are supplied) after the removal of the nervous centres, and when none were ever present; rendering it next to certain that their ordinary operations are not dependent upon any stimuli received through the nerves, but upon those directly applied to themselves. 4. The persistence of irritability in muscles for some time after the nerves have ceased to be able to convey to them the effects of stimuli; this is constantly seen in regard to the ganglionic system of nerves and the muscles of Organic life upon which they operate; and may also be shown to occur in the cerebro-spinal system and the muscles of Animal life, by the agency of narcotics. 5. The persistence of irritability in the muscles, after their complete isolation from the nervous centres, so long as their nutrition is unimpaired; and the effects of frequent exercise, in preventing the impairment of the nutrition and the loss of irritability. 6. The recovery of the irritability of muscles, when isolated from the nervous centres, after it has been exhausted by repeated stimulation; this also depends upon the healthy performance of the nutritive actions. 7. The contraction of muscular fibre under the microscope, when completely isolated from all other tissues.—In the words of Dr. Alison, then, "the only ascertained final cause of all endowments bestowed on Nerves in relation to Muscles, in the living body, appears to be, not to make Muscles irritable, but to subject their irritability, in different ways, to the dominion of the acts and feelings of the Mind,"—to its volitions, emotions, and instinctive determinations.

386. There can be no doubt, however, that the Nervous System is capable of exerting an influence upon the property itself; for we find that sudden and severe injuries of the Nervous Centres have power to impair, directly and instantaneously, or even to destroy, the contractility of the whole Muscular system; so that death immediately results, and no irritability subsequently remains. It is in this manner that the *sudden* destruction of the Brain and Spinal Cord, especially of the latter, occasion the immediate cessation of the heart's action; though they may be gradually removed without any considerable effect upon it. Severe concussion has the same effect; hence the Syncope which *immediately* displays itself. It is sometimes an important question in Forensic Medicine, whether an individual, who has died from the effects of a blow upon the head, could have moved from the place where the blow was inflicted. If there be found, as is frequently the case, no sensible disorganization of the brain, the death must be attributed to the concussion, and must have been in that case *immediate*. If, on the other hand, effusion of blood has taken place within the cranium, to any considerable extent, it is probable that the first effects of the blow were in some degree recovered from, and that the circulation was re-established. It is not essential, however, that the impression should be primarily made upon the cerebro-spinal system. The well-known fact of sudden death not unfrequently resulting from a blow on the stomach, especially after a full meal, without any perceptible lesion of the viscera, clearly indicates that an impression upon the widely-spread cœliac plexus of ganglionic nerves (which will be much more extensively communicated to them when the stomach is full than when it is empty) may cause the immediate cessation of the heart's action, in the same manner as a violent

injury of the brain or spinal cord. Now it is interesting to remark that, in all these cases, *the whole vitality* of the system appears to be destroyed at once; for the processes which would otherwise succeed the injury, and which, after other kinds of death less sudden in their character, produce evident changes in the part of the surface which has immediately received it, are here entirely prevented. An instance is on record, in which a criminal under sentence of death determined to anticipate the law by self-destruction. Having no other means of accomplishing his purpose, he stooped his head and ran violently against the wall of his cell; he immediately fell dead; and *no mark of contusion* showed itself on his forehead. The same absence of the usual results is to be noticed in the case of blows on the stomach. Yet it is well known that many of the ordinary vital processes will take place in the injured parts, after death of a more lingering nature; the vitality of the individual organs not being destroyed immediately on the severance of the chain which binds together the different functions.

387. The influence of severe impressions on the nervous system in diminishing, where it does not altogether destroy, muscular contractility, is well seen in the effect of severe injuries affecting vital organs, or extending over a large part of the surface, in depressing the heart's action. This is a well-known result of severe burns, especially in children, whose nervous system is more susceptible of such impressions than that of the adult; also of the rupture of the alimentary canal, of the bladder or uterus; and of the shattering of one of the extremities by violence affecting a large part of their substance. In all these cases, the sufferer is in the same condition with one who has received a severe blow on the head that does not quite stun him; the shock immediately diminishes the muscular contractility of the whole system; and its influence on the heart, which of course manifests itself most conspicuously, produces a degree of depression which is frequently never recovered from, and which at any rate renders necessary the employment of stimulants for the purpose of counteracting this very dangerous effect.* Excessive mental emotion, of a kind not in itself depressing, may occasion the sudden cessation of the heart's action, and a general loss of muscular contractility; and it is well known that muscular power is greatly diminished by emotions, which produce no other direct action.

388. There is no evidence that muscular irritability can be *increased* by any cause operating through the nervous system. It is well known that, under the stimulus of alcohol, nitrous oxide, &c., or of some purely mental excitement, individuals can perform actions requiring a degree of strength, which they cannot exert under any other circumstances. But it does not hence follow that the irritability is increased; since the energy of the action may be due solely to the power of the stimulus by which it is excited. It is well known that stimulating agents, which thus temporarily increase muscular power, primarily excite the nervous system, as is shown by the increased mental activity which results from the moderate use of alcohol,

* The large quantity of stimulus which can be borne even by children, suffering under severe burns, is very extraordinary. There can be no doubt that many lives have been saved by the judicious administration of them to an amount, which would *a priori* have been judged in itself fatal; but that many more have been sacrificed to neglect, even on the part of those whose duty it is to watch the indications with the closest attention. The Author's observation leads him to believe, that Hospital-Nurses very commonly make up their minds that children, who have met with severe burns, *must* die; and that, unless closely watched, they neglect the means of which Science and Experience alike dictate the free employment.

nitrous oxide, opium, &c.; and it does not seem necessary, therefore, to go further in search of an explanation of their effect on muscular action. It is worthy of remark that, whilst the influence of general depressing causes acting through the Nervous System, is primarily manifested on the muscles of Organic life, that of stimulants chiefly shows itself in the muscles subjected to the Will.

389. The last general question now to be considered regarding Muscular Contractility, is that which relates to the *Rigor Mortis*. The temporary stiffening of the body after death, from a general contraction of its muscles, is a phenomenon which is rarely absent; though it may be so slight, and may last for so short a time, as to escape observation. The period which elapses before its commencement is as variable as its duration; and both appear to be in some degree dependent upon the vital condition of the body at the time of death. When the fatal termination has supervened on slow and wasting disease, occasioning great general depression of the vital powers, the rigidity usually developes itself very early, and lasts for some time. In diseases which powerfully affect the nervous energy, such as Typhus, this is the case, even though they have not been of long duration. Thus, after death from Typhus, the limbs have been sometimes known to stiffen within 15 or 20 minutes. The same is observed in infants and in old people. On the other hand, where the general energy has been retained up to a short period before death, the rigidity is much later in coming on, and lasts longer; this happens, for example, in many cases of Asphyxia and Poisoning, in which it has been said not to occur at all. The commencement of the rigidity, however, is not usually prolonged much beyond seven hours; but twenty or even thirty hours *may* elapse before it shows itself. Its general duration is from twenty-four to thirty-six hours; but it may pass off much more rapidly; or it may be prolonged through several days. An attempt has been made to connect it with the lowering of the temperature of the dead body; but with this it does not seem to have any relation. It occurs in cold-blooded Vertebrata, and even in Invertebrata, as well as in warm-blooded animals; and it has frequently been noticed to commence in the latter, long before the heat has entirely departed from the body. Moreover, it appears first upon the trunk, which is the region last deserted by the caloric. It first affects the neck and lower jaw, and seems gradually to travel downwards; but according to some observers, the lower extremities are stiffened before the upper. In its departure, which is immediately followed by decomposition, the same order is observed. It affects all the muscles nearly alike; but the flexors are usually somewhat more contracted than the extensors, so that the fingers are somewhat flexed on the palm, and the forearm on the arm; and the lower jaw, if previously drooping, is commonly drawn firmly against the upper. It is remarkable that it is equally intense in muscles which have been paralyzed by hemiplegia, provided that no considerable change has taken place in their nutrition.

390. The muscular contraction which gives rise to the Rigor Mortis, appears to be of the same kind with that which takes place under the influence of nervous agency, though differing as to its conditions. When very strong, it renders the muscles prominent, as in voluntary contraction; and the comparative observations of Mr. Bowman upon the state of muscular fibre passing into this condition, and upon that which presented various degrees of contraction from ordinary causes, leave no doubt as to their correspondence. It is to be remarked, however, that the tendency of the muscle to contract upon the ordinary stimuli, appears to be almost invariably lost or greatly diminished before the rigor mortis commences.

This statement holds good in regard to animals of different classes, as well as to Man under various conditions. Thus in Birds, whose muscles most speedily lose their contractility, the cadaveric rigidity is most quickly exhibited; whilst in Reptiles it is much longer in commencing, the irritability of the muscles being more persistent. An attempt has been made to show a correspondence between the rigor mortis and the coagulation of the blood in the vessels; and there is certainly evidence enough to make it appear that some analogy exists between these two actions, though they are far from being identical. After those forms of death in which the blood does not coagulate, or coagulates feebly, the rigidity commonly manifests itself least, but this is by no means an invariable rule. It seems probable that, as the coagulation of the blood will be shown to be the last act of its vitality, so the stiffening of the muscles is the expiring effort of theirs. The property to which it is due, however, would appear to be of a different character from ordinary irritability. This may be inferred from the fact, that the rigidity does not ordinarily come on, until after the contractility has departed sometimes for a considerable period; and also from the circumstance observable in most cases of Asphyxia, that the rigidity is very decided and prolonged, whilst the contractility is speedily lost. This property, to which the name of Tonicity has been given, is probably the same as that which partly occasions the retraction of the muscle when divided during life; the degree of this retraction being much greater than that seen in a muscle which has been for some time dead. Moreover this kind of tonic contraction is more directly excited by heat than that which results from ordinary contractility; and it is not excited by galvanism or mechanical irritation, which so powerfully act on the latter. It is interesting, moreover, to remark that the state of habitual preponderance during sleep, of the flexor over the extensor muscles (which last are the stronger), is explicable by attributing it to the same property; the manifestations of which thus correspond, whether the contractility of the muscles be in a dormant or unexcited state, or whether it have altogether departed from the tissue.

391. It is necessary to bear in mind, when the phenomena of cadaveric rigidity are brought into question in juridical investigations, that a state at first sight corresponding to it may supervene immediately upon death, from some peculiar condition of the nervous and muscular systems at the moment. This has been observed in some cases of Asphyxia; but chiefly when death has resulted from apoplexy following chronic ramollissement of the brain or spinal cord. This contraction, which is obviously of a tetanic character, ceases after a few hours, and is then succeeded by a state of flexibility, after which the ordinary rigidity supervenes. The following case illustrates the nature of the inquiries to which this condition may give rise.* The body of a man was found in a ditch, with the trunk and limbs in such a relative position, as could only be maintained by the stiffness of the articulations. This stiffness must have come on at the very moment when the body took that position; unless it could be imagined that the body had been supported by the alleged murderers, until the joints were locked by cadaveric stiffness. A post-mortem explanation showed that there was no necessity for this supposition,—obviously a very improbable one in itself,—by affording sufficient evidence that apoplexy, resulting from chronic disease, was the cause of death. A case occurred a few years since in Scotland, in which the same plea was raised. The body was found

* Annales d'Hygiène, tom. VII.

in a position in which it could have only been retained by rigidity of the joints; and it was pleaded on the part of the prisoner that death had been natural, and had resulted from fracture of the processus dentatus causing sudden pressure upon the spinal cord, whence the spasmodic rigidity would naturally result. Proof was deficient, however, as to the existence of this lesion before death; and the position of the body rather resembled that into which it might have been forced during the rigidity, than that in which it would probably have been at the moment of death. There were also marks of violence, and many other suspicious circumstances; but the prisoner was acquitted, chiefly from want of evidence against him. What seemed to indicate that the rigidity was of the ordinary cadaveric nature, was that there was no evidence of the body having become flexible and again stiffened, as it would probably have done had the rigidity been of the spasmodic character.

Energy and Rapidity of Muscular Contraction.

392. There can be no question that, in the living body, the energy of Muscular contraction is determined, other things being equal, by the supply of arterial blood which the muscle receives. It is well known that, when a ligature is applied to a large arterial trunk in the Human subject, there is not only a deficiency of sensibility in the surface, but also a partial or complete suspension of muscular power, until the collateral circulation is established. It is evident, however, that a portion of this effect is to be ascribed to the interruption in the functions of the nervous trunks, which is due to the same cause; since muscles taken from the human body, after the circulation has entirely ceased, retain their irritability for some time. The necessity for this supply is less constant in cold-blooded than in warm-blooded animals: thus Frogs are still capable of voluntary movement, after the heart has been cut out; they can move limbs which are connected with the trunk by the nerves alone: and that this power is not altogether due to the blood which may remain in the capillary vessels, is shown by the experiment of Müller, who found the muscles still contractile, after he had expelled all the blood, by forcing a current of water into an artery, until it escaped from the divided veins. It seems probable that the Muscles of Organic life are less dependent upon a supply of arterialized blood, than are those of Animal life; for the heart will continue to contract, when the blood in its vessels is entirely venous, and when the circulation in it has come to a stand; and after its natural movements have ceased from the want of their ordinary stimulus, they may be made to recommence by a stimulus of a different kind, or by a renewal of the natural one. This is well seen in Asphyxia, in which condition (as will hereafter be explained, Chap. x,) the cessation of the action of the left ventricle is due to the stagnation of the blood in the pulmonary capillaries, whereby the supply which is necessary to excite it to action is after a time entirely checked; but if, by the introduction of oxygen into the lungs, the pulmonary circulation be renewed, the arterialized blood flowing back to the left side of the heart, re-excites its actions.

393. There is a remarkable difference in the irritability of the two sides of the heart, to which Dr. M. Hall has directed attention. In the warm-blooded Vertebrata, the right side of the heart will act on the stimulus of venous blood; whilst the left side requires the stimulus of arterial. In Fishes, on the other hand, whose heart corresponds to the right side only of that of Man, the whole is put in action by venous blood. In Reptiles,

one auricle is sufficiently stimulated by venous blood, whilst the other requires arterial; and the ventricle is excited to action by a mixed fluid. In all these cases, there must be a marked difference in the properties of the several parts; some being sufficiently affected by a stimulus, which is totally inoperative on others. This is still more remarkably exemplified by the fact, that the muscular fibre of Frogs would be thrown into a state of permanent and rigid contraction (through the powerful operation of its property of Tonicity) by the stimulus of a fluid no hotter than the blood which ordinarily bathes the muscles of Birds. Now in those warm-blooded animals which pass the winter in a state of torpidity, the respiration is very slow and imperfect, and the blood is very imperfectly arterialized. There must, therefore, be a change in the properties of the left ventricle, by which it becomes capable of action on a more feeble stimulus, thus resembling the ventricle of Reptiles. This change Dr. M. Hall designates as an *increase* of Irritability; considering that, if muscular action be excited by a more feeble stimulus, the property to which that action is due must be itself more exalted. Physiologists have been so long accustomed, however, to consider the irritability of the muscles in warm-blooded animals as greater than that of cold-blooded, on account of the greater energy and rapidity of their contractions when excited, that it seems undesirable to modify the term in the manner proposed by Dr. Hall. No one will assert that the *vitality* of the Muscle is *exalted*, when it is reduced to the condition of that of the Reptile; and, as irritability is strictly a vital property, it cannot be correctly spoken of in that manner. The general principle, however, laid down by Dr. M. Hall,—that the facility with which the muscular system may be excited to contraction, or in other words the feebleness of the stimulus required for the purpose, is inversely as the respiration of the animal,—is, no doubt, generally correct.

394. A curious question has been lately raised, the decision on which is of some importance in our determination of the nature of the force by which the contraction of muscles is occasioned. This is,—whether the power of a muscle is greater or less at different degrees of contraction, the same stimulus being applied. This seems to have been determined by the ingeniously-devised experiments of Schwann.* He contrived an apparatus which should accurately measure the length of the muscle, and, at the same time, the weight which it would balance by its contraction. Having caused the muscle to shorten to its extreme point, by the stimulus of galvanism applied to the nerve, so that no further stimulation could lift a weight placed in the opposite scale, he allowed the muscle to relax until it was extended to a certain point, and then ascertained the weight which would balance its power. The same was several times repeated, as in the following manner. The length of the muscle in its extreme state of contraction, at which no additional force could be exerted by it, being represented by 14, it was found that, when it had extended to 17, it would balance a weight of 60; when its length increased to 19·6, it would balance a weight of 120; and at 22·5, it would balance 180. In another experiment, the muscle at 13·5, balanced 0; at 18·8, it balanced 100; and at 23·4, it balanced 200. Hence it appears that an uniform increase of force is attended with a nearly uniform increase in the length of the muscle; or, in other words, that when the muscle is nearly at its full length, its contractile power is the greatest. In later experiments upon the same muscle, this uniform ratio seemed to be departed from; but, by comparing the results in a considerable number of

* Müller's Physiology, p. 903.

instances, it was constantly found that, in those experiments which were performed the soonest after the preparation of the frog, and in which, therefore, the normal conditions of the system were the least disturbed, the ratio was very closely maintained. It has been hence inferred by Müller, that the power which causes the contraction of a Muscle must be very different in its character from any of the forces of attraction known to us; since these all increase in energy as the attracted parts approach each other, in the inverse ratio of the square of the distance; so that the power of a Muscle, if operated on by any of these, ought to increase, instead of regularly diminishing, with its degree of contraction. But it is to be remembered that, as the observations of Mr. Bowman have clearly shown, there must be a considerable displacement of the constituents of every fibre during contraction (§ 371); so that it is easy to understand that, the greater the contraction, the more difficult must any further contraction become. If, between a magnet and a piece of iron attracted by it, there were interposed a spongy elastic tissue, the iron would cease to approach the magnet at a point, at which the attraction of the magnet would be balanced by the force needed to compress still further the intermediate substance.

Applications of Muscular Power.

395. The energy of Muscular contraction is of course to be most remarkably observed in those instances, in which the continual exercise of particular parts has occasioned an increased determination of blood towards them, and in consequence a permanent augmentation in their bulk. This has been the case, for example, with persons who have gained their livelihood by exhibiting feats of strength. Much will, of course, depend on the mechanically-advantageous application of muscular power; and in this manner effects may be produced, even by persons of ordinary strength, which would not have been thought credible. In lifting a heavy weight in each hand, for example, a person who keeps his back perfectly rigid, so as to throw the pressure vertically upon the pelvis, and only uses the powerful extensors of the thigh and calf, by straightening the knees (previously somewhat flexed), and bringing the leg to a right angle with the foot, will have a great advantage over one who uses his lumbar muscles for the purpose. A still greater advantage will be gained, by throwing the weight more directly upon the loins, by means of a sort of girdle shaped so as to rest upon the top of the sacrum and the ridges of the ilia; and by pressing with the hands upon a frame, so arranged as to bring the muscles of the arms to the assistance of those of the legs: in this manner a single man of ordinary strength may raise a weight of 2000 lbs., whilst few who are unaccustomed to such exertions can lift more than 300 lbs. in the ordinary mode. A man of great natural strength, however, has been known to lift 800 lbs. with his hands; and the same individual performed several other curious feats of strength, which seem deserving of being here noticed. "1. By the strength of his fingers he rolled up a very large and strong pewter dish. 2. He broke several short and strong pieces of tobacco-pipe with the force of his middle finger, having laid them on the first and third finger. 3. Having thrust in under his garter the bowl of a strong tobacco-pipe, his legs being bent, he broke it to pieces by the tendons of his hams, without altering the bending of the knee. 4. He broke such another bowl between his first and second fingers, by pressing them together sideways. 5. He lifted a table six feet long, which had half a hundred-weight hanging at the end of it, with his teeth, and held it in that position for a consider-

able time. It is true, the feet of the table rested against his knees; but, as the length of the table was much greater than its height, that performance required a great strength to be exerted by the muscles of his loins, neck, and jaws. 6. He took an iron kitchen-poker, about a yard long, and three inches in circumference, and, holding it in his right hand, he struck it on his bare left arm between the elbow and the wrist, till he bent the poker nearly to a right angle. 7. He took such another poker, and, holding the ends of it in his hands, and the middle of it against the back of his neck, he brought both ends of it together before him; and, what was yet more difficult, he pulled it straight again.*" Haller mentions an instance of a man who could raise a weight of 300 lbs., by the action of the elevator muscles of his jaw; and that of a slender girl, affected with tetanic spasm, in whom the extensor muscles of the back, in the state of tonic contraction or opisthotonos, resisted a weight of 800 lbs. laid on the abdomen with the absurd intention of straightening the body. It is to be recollected that the mechanical application of the power developed by muscular contraction to the movement of the body, is very commonly disadvantageous as regards *force*, being designed to cause the part moved to pass over a much greater *space* than that through which the muscle contracts. Thus the temporal muscle is attached to the lower jaw at about one-third of the distance between the condyle and the incisors; so that a shortening of the muscle to the amount of half an inch will draw up the front of the jaw through an inch and a half; but a power of 900 lbs. applied by the muscle would be required to raise 300 lbs. bearing on the incisors. In the case of the fore-arm and leg, the disproportion is much greater; the points of attachment of the muscles by which the knee and elbow-joints are flexed and extended, being much closer to the fulcrum, in comparison with the distance of the points on which the resistance bears.

396. The energy of muscular contraction appears to be greater in Insects, in proportion to their size, than it is in any other animals. Thus a Flea has been known to leap 60 times its own length, and to move as many times its own weight. The short-limbed Beetles, however, which inhabit the ground, manifest the greatest degree of muscular power. The *Lucanus cervus* (Stag Beetle) has been known to gnaw a hole of an inch diameter in the side of an iron canister in which it had been confined. The *Geotrupes stercorarius* (Dung or shard-borne Beetle) can support uninjured, and even elevate, a weight equal to at least 500 times that of its own body. And a small *Carabus* has been seen to draw a weight of 85 grains (about 24 times that of its body) up a plane of 25°; and a weight of 125 grains (36 times that of its body) up a plane of 5°; and in both these instances the friction was considerable, the weights being simply laid upon a piece of paper, to which the insect was attached by a string.

397. The rapidity of the changes of position of the component particles of muscular fibres, may, as Dr. Alison justly remarks,† be estimated, though it can hardly be conceived, from various well-known facts. The pulsation of the heart can sometimes be distinctly numbered in children at more than 200 in the minute; and as each contraction of the ventricles occupies only one-third of the time of the whole pulsation, it must be accomplished in $\frac{1}{600}$th of a minute, or $\frac{1}{10}$th of a second. Again, it is certain that, by the movements of the tongue and other organs of speech, 1500 letters can be distinctly pronounced by some persons in a minute; each of these must

* Desaguliers' Philosophy, vol. II.
† Cyclopædia of Anatomy and Physiology, Art. Contractility.

require a separate contraction of muscular fibres; and the production and cessation of each of the sounds implies that each separate contraction must be followed by a relaxation of equal length; each contraction, therefore, must have been effected in $\frac{1}{3000}$th part of a minute, or in the $\frac{1}{50}$th of a second. Haller calculated that, in the limbs of a dog at full speed, muscular contractions must take place in less than the $\frac{1}{200}$th of a second, for many minutes at least in succession. All these instances, however, are thrown into the shade by those which may be drawn from the class of Insects. The rapidity of the vibrations of the wings may be estimated from the musical tone which they produce; it being easily ascertained by experiments what number of vibrations are required to produce any note in the scale. From these data, it appears to be the necessary result, that the wings of many Insects strike the air *many hundred* or even *many thousand* times in every *second*. The minute precision with which the degree of muscular contraction can be adapted to the designed effect, is in no instance more remarkable than in the Glottis. The musical pitch of the tones produced by it is regulated by the degree of tension of the *chordæ vocales*, which are possesed of a very considerable degree of elasticity. According to the observations of Müller,* the average length of these, in the male, in a state of repose, is about $\frac{73}{100}$ths of an inch; whilst, in the state of greatest tension it is about $\frac{93}{100}$ths; the difference being therefore $\frac{20}{100}$ths or one-fifth of an inch: in the female glottis, the average dimensions are about $\frac{51}{100}$ths, and $\frac{63}{100}$ths respectively; the difference being thus about one-eighth of an inch. Now the natural compass of the voice, in most persons who have cultivated the vocal organ, may be stated at about two octaves, or 24 semitones. Within each semitone, a singer of ordinary capability could produce at least ten distinct intervals; so that of the total number, 240 is a very moderate estimate. There must, therefore, be at least 240 different states of tension of the vocal cords, every one of which is producible by the will, without any previous trial; and the *whole* variation in the length of the cords being not more than one-fifth of an inch, even in man, the variation required to pass from one interval to another will not be more than one-twelve hundredth of an inch. And yet this estimate is much below that which might be truly made from the performances of a practised vocalist.†

398. Of the various *associations* of muscular actions, which are employed for various purposes in the living body, it would be out of place here to speak; since these associations depend upon the nervous rather than upon the muscular system, and have already been considered in detail. It may be mentioned, however, that the aptitude which is acquired by practice for the performance of particular actions that were at first accomplished with difficulty, seems to result as much from a change which the continual repetition of them occasions in the muscle, as in the habit which the nervous system acquires of exciting their performance. Thus almost every person learning to play on a musical instrument finds a difficulty in causing the two shorter fingers to move independently of each other and of the rest; this is particularly the case in regard to the ring finger (as it is commonly termed); and any one may satisfy himself of the difficulty, by laying the palm of the hand flat on a table, and raising one finger after the other, when

* Physiology, p. 1018.

† It is said that the celebrated Mad. Mara was able to sound 100 different intervals between each tone. The compass of her voice was at least three octaves, or 22 tones; so that the total number of intervals was 2200, all comprised within an extreme variation of one-eighth of an inch; so that it might be said that she was able to determine the contractions of her vocal muscles to the seventeen-thousandth of an inch.

it will be found that the ring-finger cannot be lifted without disturbing the rest,—evidently from the difficulty of detaching the action of that portion of the extensor communis digitorum by which the movement is produced, from that of the remainder of the muscle. Yet to the practised musician, the command of the will over all the fingers becomes nearly alike; and it can scarcely be doubted that some change takes place in the structure of the muscle, which favours the isolated operation of its several divisions.

Sensibility of Muscles.

399. Muscles are much less sensible to external impressions than many other parts of the body; this is seen in amputations, in which the severest pain caused by the section is that of the incision through the skin. It is well known that a needle passed through the skin may be carried into the substance of a muscle with scarcely any further pain; and the heart laid bare has been observed to possess but a very slight degree of sensibility. This is easily accounted for by our knowledge of the distribution of the nerves; for although every principal trunk may contain motor and sensory nerves in equal proportion, we know that in its various subdivisions these may be very unequally distributed. Thus, in the third division of the Fifth pair, it has been ascertained that the fibres from the motor root chiefly pass into the muscular branches, whilst those of the sensory root predominate in those supplying the surface; and in the Par Vagum a difference in the endowments of the several branches has been equally substantiated. Again, in the Orbit, we find some muscles supplied by nerves which are exclusively motor, and scarcely receiving any sensory branches from the Fifth pair. Knowing as we do, that the general surface of the body would not derive any advantage from receiving the motor division of the Spinal nerves, and must on the contrary be largely supplied from the sensory, it cannot be doubted that, with regard to the subjacent muscles, the case is entirely the reverse. Muscles are endowed, however, with the power of originating sensations indicative of their own condition; and these sensations differ so far from those conveyed by the usual sensory organs, that it has been proposed to designate the channel through which they are received by a peculiar name, the *Muscular Sense.* It may be questioned, however, whether this is desirable. The property by which we estimate the force with which muscles are contracting,—which enables us to compare different degrees of weight and resistance, and to acquire a knowledge of the distances and relative positions of bodies brought in contact with the surface,—appears to be the same with that by which we become conscious of fatigue from continued muscular action, and experience pain when the muscles are spasmodically contracted, as in ordinary cramp. Of the importance of this sense in guiding and regulating muscular contraction, instances have already been given (§ 257). It is, in addition, one of the principal means by which we acquire our notions of the external world. All our ideas of *force* and of *resistance* are derived from it. When we put our muscles in action to raise a weight, or to push from us an obstacle, we should have no idea, without this sense, of the effort required: and it is obvious, on a little consideration, that no statements of any natural forces (such as that of Gravitation, Magnetic Attraction, &c.) could convey a distinct idea to our minds, were it not for our means of estimating them by the same means. It is by the sensibility of the muscles that we become conscious of the existence and direction of motion, to which the whole body is being passively subjected. When sitting upright in a carriage, which is suddenly

drawn forwards, we are thrown in the contrary direction; and it is only by a certain muscular effort that we can regain our position. After some little time, however, we become so habituated to the sensation which this occasions, that we are unconscious of it, except by a certain degree of fatigue which results, if it be greatly prolonged. But when the motion suddenly ceases, we are thrown forwards, showing that the effort itself had continued; and not unfrequently the feeling of motion is then experienced for a few seconds, as if the sensation remained, and were more perceptible when the cause of it had ceased.

Other Contractile Tissues.

400. Although the Muscular tissue is the only one, besides the Nervous, that can be said to be the instrument of the Animal functions,—since upon it alone the mind can operate,—it is by no means the only tissue in the Human body which is able to exhibit the property of Contractility on the application of a stimulus. The Skin, for example, may be made to contract by the agency of cold; as appears from the production of the *cutis anserina*,—a phenomenon of a strictly vital character, which cannot be explained by any physical causes. In this, the subcutaneous Cellular Tissue appears to participate. The Dartos has a similar contractile power in a higher degree; this tissue is a peculiar modification of the ordinary subcutaneous cellular substance; and its fibres resemble those of which that tissue is composed, being uniform cylinders varying from about $\frac{1}{2000}$th to $\frac{1}{1100}$th of a line in diameter, and consequently much smaller than muscular fibres; and they further correspond with those of cellular tissue in their elasticity and serpentine disposition. It is so closely united to the skin, that the latter must follow all its movements; and to this cause is due the wrinkling of the scrotum under the influence of cold. It would appear that the contractility of the dartos may be excited through the nervous system; since the same cause which produces the contraction of a true muscle—the cremaster, occasions the wrinkling of the scrotum, when no direct stimulus is operating on the latter. The fibrous tissue which forms the middle coat of the arteries is probably more allied to muscle in its structure and properties, than either of those just adverted to; its nature and uses will be treated of in detail hereafter (CHAP. IX).

CHAPTER VI.

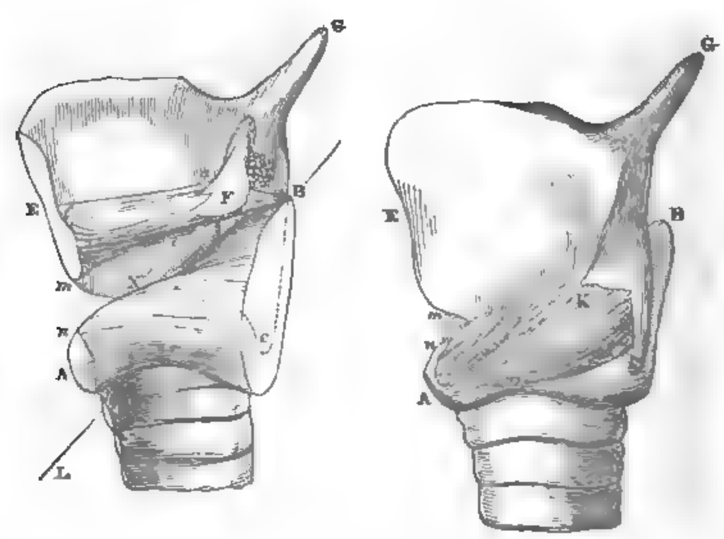
Of the Voice and Speech.

401. The sounds produced by the organ of Voice constitute the most important means of communication between Man and his fellows; and the power of speech has, therefore, a primary influence, as well on his physical condition, as on the development of his mental faculties. Hence, although it only depends on one particular application of muscular force, comparable to that by which other volitional or emotional movements are effected, it seems right, in treating of the Physiology of Man, to make it an object of special consideration. In order to understand the nature of the Organ of Voice as a generator of Sound, it is requisite to inquire, in the first instance,

into the sources from which sounds at all corresponding to the human voice are elsewhere obtained. It is necessary to bear in mind that Vocal Sounds, and Speech or Articulate Language, are two things entirely different; and that the former may be produced in great perfection, where there is no capability for the latter. Hence we should at once infer, that the instrument for the production of Vocal Sounds was distinct from that by which these sounds are modified into articulate speech; and this we easily discover to be the case,—the Voice being unquestionably produced in the Larynx, whilst the modifications of it by which language is formed, are effected for the most part in the oral cavity. The structure and functions of the former, then, first claim our attention.

402. It will be remembered that the windpipe is surmounted by a stout bony annulus, termed the *Cricoid* cartilage, which serves as a foundation for the superjacent mechanism. This is embraced (as it were) by the *Thyroid*, which is articulated to its sides by its lower horns, round the extremities of which it may be regarded as turning, as on a pivot. In this manner the lower front border of the thyroid cartilage, which is ordinarily separated by small intervals from the upper margin of the thyroid, may be made to approach it or recede from it; as any one may easily ascertain, by placing his finger against the little depression which may be readily felt externally, and observing its changes of size, whilst a range of different tones is sounded; it will then be observed that, the higher the note, the more the two cartilages are made to approximate,—whilst they separate in proportion to the depth of the tones.* Upon the upper surface of the back of the cricoid are seated

Fig. 36.

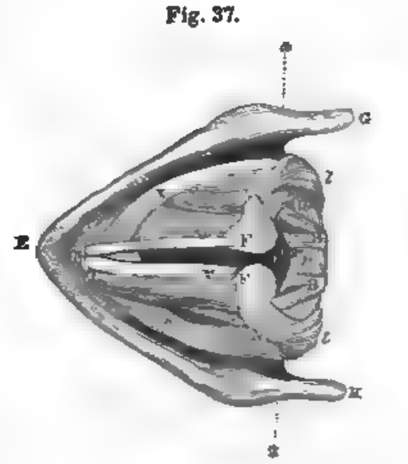


External and sectional views of the Larynx, after Willis. A n B, the cricoid cartilage; E G C, the thyroid cartilage; G, its upper horn; C, its lower horn, where it is articulated with the cricoid; F, the arytenoid cartilage; B, F, the vocal ligament; A K, crico-thyroideus muscle; F e m, thyro-arytenoideus muscle; K e, crico-arytenoideus lateralis; s, transverse section of arytenoideus transversus; m n, space between thyroid and cricoid; B L, projection of axis of articulation of arytenoid with thyroid.

* In making this observation, it is necessary to put out of view the general movement of the larynx itself, which the finger must be made to follow up and down.

the two small *Arytenoid* cartilages; these are fixed in one direction by a bundle of strong ligaments, which tie them to the back of the cricoid; but they have some power of moving in others upon a kind of articulating surface. The direction of the surface, and the mode in which these cartilages are otherwise attached, cause their movement to be a sort of rotation in a plane which is nearly horizontal, but partly downwards, so that their vertical planes may be made to separate from each other, and at the same time to assume a slanting position. This change of place will be better understood, when the action of the muscles is described. To the summit of the arytenoid cartilages are attached the *chordæ vocales* or vocal ligaments, which stretch across to the front of the thyroid cartilage; and it is upon the condition and relative situation of these ligaments, that their action depends. It is evident that they may be rendered more or less tense, by the movement of the thyroid cartilage just described; being tightened by the depression of its front upon the cricoid cartilage, and slackened by its elevation. On the other hand, they may be brought into more or less close apposition by the movement of the arytenoid cartilages; being made to approximate closely, or to recede in such a manner as to cause the rima glottidis to assume the form of a narrow V, by the revolution of these cartilages. We shall now inquire into the actions of the muscles upon the several parts of this apparatus; and first into those of the larynx alone.

Fig. 37.

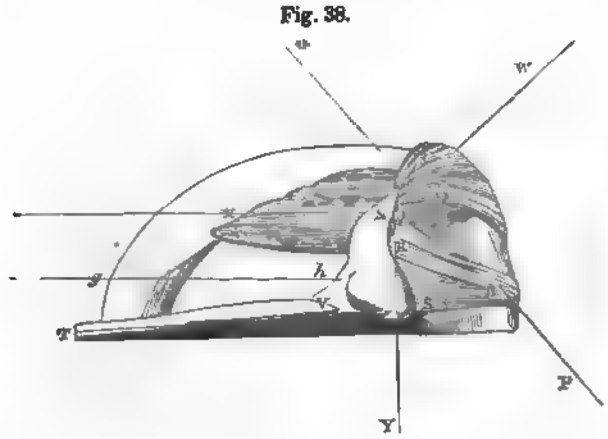


Bird's-eye view of larynx from above, after Willis. G E H, the thyroid cartilage, embracing the ring of the cricoid r s x w, and turning upon the axis x x, which passes through the lower horns, c, Fig 36; N F, N F, the arytenoid cartilages, connected by the arytenoideus transversus; T V, T V, the vocal ligaments; N X, the right crico-arytenoideus lateralis (the left being removed); V k f, the right thyro-arytenoideus (the left being removed; N l, N l, the crico-arytenoidei postici, R R, the crico-arytenoid ligaments.

408. The depression of the front of the Thyroid cartilage, and the consequent tension of the vocal ligaments, is occasioned by the conjoint action of the *Crico-thyroideus* on either side; and the chief antagonist to this is the *Thyro-arytenoideus*, which draws the front of the Thyroid back towards the Arytenoid cartilages, and thus relaxes the vocal ligaments. These two muscles may be regarded as the principal governors of the pitch of the notes, which, as we shall hereafter see, is almost entirely regulated by the tension of the ligaments; their action is assisted, however, by that of other muscles presently to be mentioned. The arytenoid cartilages are made to diverge from each other by means of the *Crico-arytenoideus posticus* of each side, which proceeds from their outer corner, and turns somewhat round the edge of the Cricoid, to be attached to the lower part of its back; its action is to draw the outer corner backwards and downwards, so that the points to which the vocal ligaments are attached are separated from one another, and the rima glottidis is thrown open. This will be at once seen from the subjoined diagram, in which the direction of action of the several muscles is laid down. The action of this muscle is partly antagonized by that of the *Crico-arytenoideus*, which runs forwards and downwards from the outer

corner of the arytenoid cartilage; and its action, with that of its fellow, will be to bring the anterior points of the arytenoid cartilages into the same straight line, at the same time depressing them, and thus to close the glottis. This muscle is assisted by the *Arytenoideus transversus*, which connects

Fig. 38.



Part of Fig. 37 enlarged, to show the direction of the muscular forces, which act on the arytenoid cartilage. e N V e, the right arytenoid cartilage; T V, its vocal ligament; R R s, bundle of ligaments uniting it to cricoid, O P, projection of its axis of articulation; *h g*, direction of the action of the thyro-arytenoideus; N X, direction of crico-arytenoideus lateralis; N W, direction of crico-arytenoideus posticus; N Y, direction of arytenoideus transversus. After Willis.

the posterior faces of the arytenoid cartilages, and which, by its contraction, will draw them together. By the conjoint action, therefore, of the Crico-arytenoideus lateralis, and of the Arytenoideus transversus, the whole of the adjacent faces of the arytenoid cartilages will be pressed together; and the points to which the vocal ligaments are attached will be depressed. But if the Arytenoideus be put in action in conjunction with the Crico-arytenoidei postici, the tendency of the latter to separate the arytenoid cartilages being antagonized by the former, its backward action only will be exerted; and thus it may be caused to aid the Crico-thyroideus in rendering tense the vocal ligaments. This action will be further assisted by the *Sterno-thyroideus*, which tends to depress the Thyroid cartilage, by pulling from a fixed point below;* and the *Thyro-hyoideus* will be the antagonist of this, when it acts from a fixed point above, the Os Hyoides being secured by the opposing contraction of several other muscles. The respective actions of these muscles will be best comprehended by the following table.

Govern the pitch of the notes.

Antagonists.	CRICO-THYROIDEI STERNO-THYROIDEI	Depress the front of the Thyroid cartilage on the Cricoid, and *stretch* the vocal ligaments; assisted by the Arytenoideus and Crico-arytenoidei postici.
	THYRO-ARYTENOIDEI THYRO-HYOIDEI	Elevate the front of the Thyroid cartilage, and draw it towards the Arytenoids, *relaxing* the vocal ligaments.

* This is not usually reckoned as one of the principal muscles concerned in regulating the voice; but that it is so, any one may convince himself by placing his finger just above the sternum, whilst he is sounding high notes; a strong feeling of muscular tension is then at once perceived.

Govern the Aperture of the Glottis.

Antagonists.	Crico-Arytenoidei postici	*Open* the Glottis.
	Crico-Arytenoidei laterales Arytenoideus	Press together the inner edges of the Arytenoid cartilages, and *close* the Glottis.

404. The muscles which stretch or relax the Vocal ligaments are entirely concerned in the production of Voice; those which govern the aperture of the glottis have important functions in connection with the Respiratory actions in general, and stand as guards (so to speak) at the entrance to the lungs. Their separate actions are easily made evident. We can close the aperture of the glottis, by an exertion of the will, either during inspiration or expiration; and it is a kind of spasmodic movement of this sort, which is concerned in the acts of Coughing and Sneezing, as well as in the more prolonged impediments to the ingress and egress of air, which have been already noticed as resulting from disordered states of the Nervous system (§ 300). A slight examination of the recent Larynx is sufficient to make it evident that, when once the borders of the rima glottidis are brought together by muscular action, the effect of strong aerial pressure on either side,—whether produced by an expulsory blast from below, or by a strong inspiratory effort occasioning a partial vacuum below and a consequently increased pressure above,—will be to force them into closer apposition. With this action, then, the muscles which regulate the tension of the vocal ligaments have nothing to do. In the ordinary condition of rest, it seems probable that the Arytenoid cartilages are considerably separated from each other; so as to cause a wide opening to intervene between their inner faces, and between the vocal ligaments, through which the air freely passes: and the vocal ligaments are at the same time in a state of complete relaxation. In order to produce a vocal sound, it is not sufficient to put the ligaments into a state of tension; they must also be brought nearer to each other. That the aperture of the glottis is greatly narrowed during the production of sounds is easily made evident to oneself, by comparing the time occupied by an ordinary expiration, with that required for the passage of the same quantity of air during the sustenance of a vocal tone. Further, the size of the aperture is made to vary in accordance with the note which is being produced; of this, too, any one may convince himself, by noting the time during which he can hold out a low and a high note; from which it will appear that the aperture of the glottis is so much narrowed in producing a high note, as to permit a much less rapid passage of air than is allowed when a low one is sounded. This adjustment of the aperture to the tension of the vocal ligaments is a necessary condition of the production of a clear and definite tone. It further appears that, in the narrowing of the glottis which is requisite to bring the vocal ligaments into the necessary approximation, the upper points of the arytenoid cartilages are caused to approximate, not only by being made to rotate horizontally towards each other, but also by a degree of elevation; so that the inner faces of the vocal ligaments are brought into parallelism with each other,—a condition which may be experimentally shown to be necessary for their being thrown into sonorous vibration.

405. We have now to inquire what is the operation of the Vocal Ligaments in the production of sounds; and in order to comprehend this, it is necessary to advert to the conditions under which tones are produced by

instruments of various descriptions having some analogy with the larynx. These are chiefly of three kinds,—strings, flute-pipes, and reeds or tongues. The vocal ligaments were long ago compared by Ferrein to vibrating strings; and at first sight there might seem a considerable analogy, the sounds produced by both being elevated by increased tension. This resemblance disappears, however, on more accurate comparison; for it may be easily ascertained by experiment, that no string so short as the vocal ligaments could give a clear tone at all to be compared in depth with that of the lowest notes of the human voice; and also, that the scale of changes produced by increased tension is fundamentally different. When strings of the same length, but of different tension, are made the subject of comparison, it is found that the number of vibrations is in proportion to the square roots of the extending forces. Thus, if a string extended by a given weight produce a certain note, a string extended by four times that weight will give a note in which the vibrations are twice as rapid,—and this will be the octave of the other. If nine times the original weight be employed, the vibrations will be three times as rapid as those of the fundamental note, producing the twelfth above it. Now by fixing the larynx in such a manner, that the vocal ligaments can be extended by a known weight, Müller has ascertained that the sounds produced by a variation of the extending force will not follow the same ratio; and therefore the condition of these ligaments cannot be simply that of vibrating cords. Further, a cord of certain length, which is adapted to give out a clear and distinct note, equal in depth to the lowest of the human voice, may be made by increased tension to produce all the superior notes, which, in stringed instruments, are ordinarily obtained by shortening the strings.* But it does not follow that a short string, which, with moderate tension, naturally produces a high note, should be able, by a diminution of the tension, to give out a deep one; for, although this might be theoretically possible, yet it cannot be accomplished in practice; since the vibrations become irregular on account of the diminished elasticity.† These considerations are in themselves sufficient to destroy the supposed analogy; and to prove that the Chordæ Vocales cannot be reduced to the same category with vibrating strings.

406. The next kind of instrument with which some analogy might be suspected, is the Flute-pipe, in which the sound is produced by the vibration of an elastic column of air contained in the tube; and the pitch of the note is determined almost entirely by the length of the column, although slightly modified by its diameter, and by the nature of the embouchure or mouth from which it issues. This is exemplified in the German Flute and in the English Flute or Flageolet; in both of which instruments the acting length of the pipe is determined by the intervals between the embouchure and the nearest of the side apertures; by opening or closing which, therefore, a modification of the tone is produced. In the Organ, of which the greater number of pipes are constructed upon this plan, there is a distinct pipe for every note; and their length increases in a regular scale. It is, in

* Thus in the Piano-forte, where there are strings for each note, a gradual shortening is seen from the lowest to the highest; and in the Violin, the change [illegible] is produced by *stopping* the strings with the finger [illegible] length.

† Thus it would be impossible to produce good Bass notes [illegible] Violin, by diminishing their tension, [illegible] by the Violoncello or Double Bass is requisite. The [illegible] Grand Piano-forte and [illegible] upright P[illegible] another exemplification [illegible] the same principle, being chiefly due to the length and tension of the former, as contrasted with the shortness and slackness of the latter

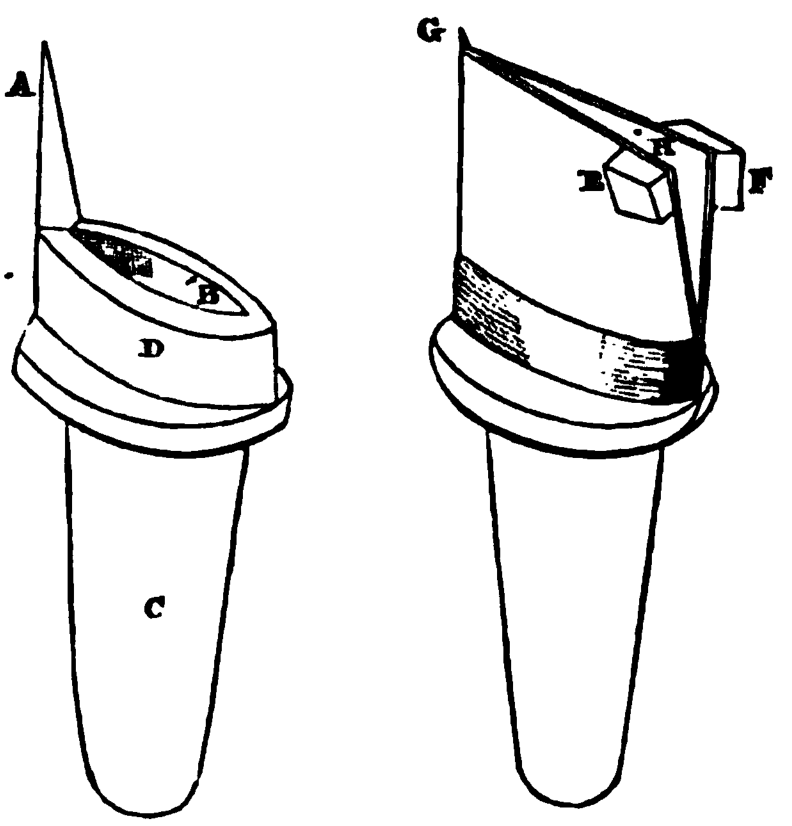
fact, with flute-pipes as with strings,—that a diminution in length causes an increase in the number of vibrations in an inverse proportion; so that of two pipes, one half the length of the other, the shorter will give a tone which is the octave above the other, the vibrations of its column of air being twice as rapid. Now there is nothing in the form or dimensions of the column of air between the larynx and the mouth, which can be conceived to render it at all capable of such vibrations as are required to produce the tones of the Human voice; though there is some doubt whether it is not the agent in the musical tones of some Birds. The length of an open pipe necessary to give the lowest G of the ordinary bass voice, is nearly six feet; and the conditions necessary to produce the higher notes from it, are by no means those which we find to exist in the process of modulating the human voice.

407. We now come to the third class of instruments, in which sound is produced by the vibration of reeds or tongues; these may either possess elasticity in themselves, or be made elastic by tension. The reeds of the Mouth-Æolina, Accordion, Seraphine, &c., are examples of instruments of this character, in which the lamina vibrates freely in a sort of frame, that allows the air to pass out on all sides of it through a narrow channel, thus increasing the strength of the blast: whilst in the Hautboy, Bassoon, &c., and in Organ-pipes of similar construction, the reed is attached to one end of a pipe. In the former kind, the sound is produced by the vibration of the tongue alone, and is regulated entirely by its length and elasticity; whilst in the latter, its pitch is dependent upon this conjointly with the length of the tube, the column of air contained in which is thrown into simultaneous vibration. Some interesting researches on the effect produced on the pitch of a sound given by a reed, through the union of it with a tube, have been made by M. W. Weber; and, as they are important in furnishing data by which the real nature of the vocal organ may be determined, their chief results will be here given. I. The pitch of a reed may be lowered, but cannot be raised, by joining it to a tube. II. The sinking of the pitch of the reed thus produced is at the utmost not more than an octave. III. The fundamental note of the reed thus lowered may be raised again to its original pitch by a further lengthening of the tube; and by a further increase is again lowered. IV. The length of tube necessary to lower the pitch of the instrument to any given point depends on the relation which exists between the frequency of the vibrations of the tongue of the reed and those of the column of air in the tube, each taken separately.—From these data, and from those of the preceding paragraph, it follows that, if a wind-instrument can, by the prolongation of its tube, be made to yield tones of any depth in proportion to the length of the tube, it must be regarded as a flute-pipe; whilst, if its pitch can only be lowered an octave or less (the embouchure remaining the same) by lengthening the tube, we may be certain that it is a reed instrument. The latter proves to be the case in regard to the Larynx.

408. Between the action of the Chordæ Vocales, however, and that of an ordinary reed, there appears to be a marked difference; but this difference is really by no means considerable. In a reed, elasticity is a property of the tongue itself, when fixed at one end, the other vibrating freely; but by a membranous lamina, fixed in the same manner, no tone would be produced. If such a lamina, however, be made elastic by a moderate degree of tension, and be fixed in such a manner as to be advantageously acted on by a current of air, it will give a distinct tone. It is observed by Müller that membranous tongues made elastic by tension, may have either of three different forms. I. That of a band extended by a cord, and included between two firm plates, so that there is a cleft for the passage of

air on each side of the tongue. II. The elastic membrane may be stretched over the half or any portion of the end of a short tube, the other part being occupied by a solid plate, between which and the elastic membrane a narrow fissure is left. III. Two elastic membranes may be extended across the mouth of a short tube, each covering a portion of the opening, and having a chink left open between them.—This last is evidently the form most allied to the Human Glottis; but it may be made to approximate still more closely, by prolonging the membranes in a direction parallel to that of the current of air, so that not merely their edges but their whole planes shall be thrown into vibration. Upon this principle a kind of artificial glottis has been constructed by Mr. Willis, the conditions of action and the effects of which are so nearly allied to that of the real instrument, that the similar character of the two can scarcely be doubted. The following is his description of it. "Let a wooden pipe be prepared of the form of Fig. 39, having a foot C like that of an organ-pipe, and an upper opening, long and narrow, as at B, with a point A rising at one end of it. If a piece of leather, or still better, of sheet India Rubber be doubled round this point, and secured by being bound round the pipe at D with strong thread, as in Fig. 39*, it will give us an artificial glottis with its upper edges G H, which may be made to vibrate or not, at pleasure, by inclining the planes of the edges. A couple of pieces of cork may be glued to the corners to make them more manageable. From this machine various notes may be obtained, by stretching the edges in the direction of their length G H; the notes rising in pitch with the increased tension, although the length of the vibrating edge is increased. It is true that a scale of notes equal in extent to that of the human voice cannot be obtained from edges of leather; but this scale is much greater in India Rubber than in leather; and the elasticity of them both is so much inferior to that of the vocal ligaments, that we may readily infer that the great scale of the latter is due to its greater elastic powers." By other experimenters the tissue forming the middle coat of the arteries has been used for this purpose, in the moist state, with great success; with this the tissue of the vocal ligaments is nearly identical. It is worthy of remark that, in all such experiments, it is found that the two membranes may be thrown into vibration when inclined *towards* each other in various degrees, or even when they are in the same plane, and their edges only approximate; but that the least inclination *from* each other (which is the position the vocal ligaments have during the ordinary state of the glottis, § 404) completely prevents any sonorous vibrations from being produced.

Fig. 39. Fig. 39.*



Artificial larynx.

409. The pitch of the note produced by membranous tongues may be affected in several ways. Thus, an increase in the strength of the blast, which has little influence on metallic reeds, raises their pitch very considerably; and in this manner the note of a membranous reed may be raised

by semitones to as much as a fifth above the fundamental. The addition of a pipe has nearly the same effect on their pitch as on that of metallic reeds; but it cannot easily be determined with the same precision. The effect of the junction of a pipe with a double membranous tongue is well shown in the Trumpet, Horn, and other instruments, which require the vibration of the lips, as well as a blast of air, for the production of their sound, having no reed of their own. By some, these instruments have been classed with Flute-pipes; but the conditions of their action are entirely different. The mouth-piece of the horn or trumpet is incapable of yielding any tone, when a current of air is merely blown through it; and the lips are necessary to convert it into a musical reed, being rendered tense by the contraction of their sphincter, partly antagonized by the slightly-dilating action of other muscles. The variation of the tension of the lips is effected by muscular effort; and several different notes may be produced with a pipe of the same length: but there is a length of the column of air which is the one best adapted for each tone; and different instruments possess various contrivances for changing this. It has been recently ascertained, that the length of the pipe prefixed to the reed has also a considerable influence on its tone, rendering it deeper in proportion as it is prolonged, down to nearly the octave of the fundamental note; but the pitch then suddenly rises again, as in the case of the tube placed beyond the reed. The researches of Müller, however, have not succeeded in establishing any very definite relation between the length of the two tubes, in regard to their influence on the pitch of the reed placed between them.

410. From the foregoing statements it appears, that the true theory of the Voice may now be considered as well established, in regard to this essential particular,—that the sound is the result of the vibrations of the vocal ligaments, which take place according to the same laws with those of metallic or other elastic tongues: and that the pitch of the notes is chiefly governed by the tension of these laminæ. With respect, however, to the modifications of these tones induced by the shape of the air-passages, both above and below the larynx, by the force of the blast, and by other concurrent circumstances, little is certainly known. Hence it is that on the theory of the production of what are called *falsetto* notes, there is much difference of opinion amongst physiologists. Some have contended, that these tones are produced by the vibration of the vocal ligaments along only a part of their length; but this is certainly untrue. By Müller it is believed that in the falsetto notes merely the thin border of the glottis vibrates, so that the fissure remains distinctly visible; whilst in the production of the ordinary vocal tones, the whole breadth of the vocal ligaments is thrown into strong vibrations, which traverse a wider sphere, so that a confused motion is seen in the lips of the glottis, and its fissure is obscured. That the tension of the vocal cords is not diminished (as it ought to be if only a part of their length were being used), but is progressively increased, as we pass from the ordinary falsetto scale, any one may convince himself, by placing his finger on the interval between the thyroid and cricoid cartilages, as formerly described (§ 402).* A very important adjunct to the produc-

* That the falsetto voice differs in some essential particular from the natural, is evident from this,—that many persons who possess a considerable range of both are yet unable to unite them, so as to sing through the whole scale without a marked interruption. Thus a gentleman of the Author's acquaintance has a bass voice, ranging from the lowest E of the Square Piano to the second C above; and a falsetto ranging from the A below this to the E of the octave above, so as to give a compass of three octaves on the whole; yet the two registers cannot be smoothly blended.

tion of the higher notes has been pointed out by Müller, as being afforded by the modification in the space included between the two sides of the thyroid cartilage, which is effected by the thyro-arytenoidei. He had experimentally ascertained that the introduction of a hollow plug into the upper end of the pipe beneath his artificial larynx (and therefore just below the reed), by diminishing its aperture, produced a considerable elevation of the tone. The action may be imitated in the human larynx, when made the subject of experiment, by compressing laterally the thyroid cartilage; and in this manner the natural voice could be made to extend through a range that could otherwise be only reached by a falsetto.

411. The strength of the tone produced in the larynx is much increased by the resonance of the elastic tissue which it contains in various other parts; but still more, perhaps, by that produced by the air in the trachea, bronchi, and pulmonary cells. This comes to be of great importance in the phenomena of auscultation. The aerial resonance is loudest where any large body of air is collected together, as in the trachea, the larger bronchi, an emphysematous dilatation, or a cavity resulting from tubercular softening. On the other hand, solidification of the pulmonary tissue will produce a resonance of a somewhat different kind. The influence of the prefixed and superadded tubes, in modifying the tones produced by the Human larynx, has been found by Prof. Müller not to be at all comparable to that which they exercised over the artificial larynx; the reason of which difference does not seem very apparent. It appears, however, that there is a certain length of the prefixed tube,—as there is a certain distance of the vibrating laminæ, and a certain length or form of the tube above,—which is most favourable to the production of each note; and the downward movement of the whole vocal organ, which takes place when we are sounding deep notes, and its rise during the elevation of the tones, have been supposed to have the purpose of making this adjustment in the length of the trachea; but this requires the supposition that the real length of the trachea is shortened whilst it appears extended,—for which there seems no foundation. It is imagined by Mr. Wheatstone, that the column of air in the trachea may divide itself into harmonic lengths, and may produce a *reciprocation* of the tone given by the vocal ligaments (§ 353); and in this manner he considers that the falsetto notes are to be explained. It may be added that the partial closing of the epiglottis seems to assist in the production of deep notes, just as the partial covering of the top of a short pipe fixed to a reed, will lower its tone: that something of this kind takes place during natural vocalization would appear, from the retraction and depression of the tongue which accompany the lowering of the front of the head, when the very lowest notes are being sounded. The arches of the palate and uvula become contracted during the formation of the higher tones; but no difference can be perceived in their state, whether these tones be falsetto or not; hence it would appear that they have no concern in this peculiarity; and the purpose of their increased tension is probably to maintain their power of resonance. The experiments of Savart have shown, that a cavity which only responds to a shrill note, when its walls are firm and dry, may be made to afford a greater variety of lower tones, when its walls are moistened and relaxed in various degrees. This observation may probably be applied also to the trachea.

412. These and numerous other muscular actions which are employed in the production and regulation of the voice, are effected by an impulse which can scarcely be termed voluntary, and the nature of which is a curious subject for inquiry. It may be safely affirmed that the production of

sounds is in itself an instinctive action, although the combination of these, whether into music or articulate language, is a matter of acquirement. Now it might be supposed that the will had sufficient power over the vocal muscles, to put them into any state requisite for its purposes, without any further condition; but a little self-experiment will prove, that this is not the case. No definite tone can be produced by a voluntary effort, unless that tone be present to the mind, during however momentary an interval, either as immediately conveyed to it by an act of Sensation, recalled by an act of Conception, or anticipated by an effort of the Imagination. When thus present, the will can enable the muscles to assume the condition requisite to produce it; but under no other circumstances does this happen, except by a particular mode of discipline presently to be adverted to. The action itself, therefore, must be reduced to the class of consensual movements; and we must suppose that the will is exercised in permitting rather than in directly exciting it. That those who are unfortunately labouring under congenital deafness are thence debarred from learning the use of voice in the ordinary manner, is well known; the consensual action cannot be excited, either through sensations of the present, or conceptions of the past; and the imagination is entirely destitute of power to suggest that which has been in no shape experienced. But such persons may be taught to speak in an imperfect manner, by causing them to imitate particular muscular movements which they may be made to see; and it is evident that they must be guided in the imitation and ordinary performance of those movements, by the common muscular sensations which accompany them, and not by the sensations conveyed through the auditory nerve, which are for this purpose by far the most precise guides. Many instances, indeed, are on record, in which persons entirely deaf were enabled to carry on a conversation in the regular way; judging of what was said, by the movements of the lips and tongue, which they had learned to connect with particular syllables; and regulating their own voices in reply, by their voluntary power, guided by muscular sensation.*

[In the foregoing account of the Physiology of Voice, the Author has been chiefly guided by the excellent paper by Mr. Willis in the Transactions of the Cambridge Philosophical Society, Vol. iv., and by the elaborate investigations of Müller and his coadjutors, as detailed in the Fourth Book of his Physiology.]

Of Articulate Sounds.

413. The Larynx, as now described, is capable of producing those *tones* of which Voice fundamentally consists, and the sequence of which becomes Music; but Speech consists in the modification of the laryngeal tones by other organs intervening between the glottis and the os externum, so as to produce those *articulate sounds* of which Language is formed. It cannot be questioned that Music has *its* language, and that it is susceptible of expressing the emotional states of the mind, among those at least who have been accustomed to associate these with its varied modes, to even a higher degree than articulate speech. But it is incapable of addressing the intellect, by conveying definite ideas of objects, properties, actions, &c., in any other way than by a kind of imitation, which may be compared to the signs used in hieroglyphic writing. These ideas it is the peculiar province of articulate language to convey; and we find that the vocal organ is adapted to form a large number of simple sounds, which may be readily combined into

* See Johnstone on Sensation, p. 128.

groups, forming words: the number of combinations which can be thus produced, is so inexhaustible, that every language has its own peculiar series, no difficulty being found in forming new ones to express new ideas. There is considerable diversity in different languages, even with regard to the use of the simplest of these combinations; some of them are more easy of formation than others, and these accordingly enter into the composition of all languages; whilst of the more difficult ones, some are employed in one language, some in another,—no one possessing them all. Without entering into any detailed account of the mechanism required to produce each of these simple sounds, a few general considerations will be offered in regard to the classification of them; and the peculiar defect of articulation termed Stammering will be briefly treated of.

414. Vocal sounds are divided into Vowels and Consonants; and the distinctive characters of these are usually considered to be, that the Vowels are produced by the Voice alone, whilst the sound of the Consonants is formed by some kind of interruption to the voice, so that they cannot be properly expressed unless conjoined with a vowel. The distinction may be more correctly laid down, however, in this manner;—the vowel sounds are continuous tones, modified by the form of the aperture through which they pass out; whilst in sounding consonants, the breath suffers a more or less complete interruption in its passage through parts anterior to the larynx. Hence the really simple vowel sounds are capable of prolongation during any time that the breath can sustain them; this is not the case, however, with the real diphthongal sounds (of which it will presently appear that the English *ī* is one); whilst it is true of some consonants. It seems to have been forgotten by many of those who have written on this subject, that the laryngeal voice is not essential to the formation of either vowels or consonants; for all may be sounded in a whisper. It is very evident, therefore, that the larynx is not primarily concerned in their production; and this has been fully established by the following experiment. A flexible tube was introduced by M. Deleau through his nostrils into the pharynx, and air was impelled by it into the fauces; then, closing the larynx, he threw the fauces into the different positions requisite for producing articulate sounds, when the air impelled through the tube became an audible whisper. The experiment was repeated, with this variation,—that laryngeal sounds were allowed to pass into the fauces; and each articulated letter was then heard double, in a proper voice and in a whisper.

415. That the Vowels are produced by simple modifications in the form of the external passages, is easily proved both by observation and by imitative experiment. When the mouth is opened wide, the tongue depressed, and the velum palati elevated, so as to give the freest possible exit to the voice, the vowel *a* in its broadest form (as in *ah*) is sounded.* On the other hand, if the oral aperture be contracted, the tongue being still depressed, the sound *oo* (the continental *u*) is produced. If attention be paid to the state of the buccal cavity during the pronunciation of the different vowel sounds, it will be found to undergo a great variety of modifications, arising from varieties of position of the tongue, the cheeks, the lips, and of the velum palati. The position of the tongue is, indeed, one of the primary conditions of the variation of the sound; for it may be easily ascertained that, by peculiar inflexions of this organ, a great diversity of vowel sounds may be

* The sound of the vowel *a* is scarcely used in our language, though very common in most of the continental tongues, the nearest approach to it in English is the *a* in *far;* but this is a very perceptible modification, tending towards *aw*.

produced, the other parts remaining the same. Still there is a certain position of all the parts, which is most favourable to the formation of each of these sounds; but this could not be expressed without a lengthened description; the following table, slightly altered from that of Kempelen, expresses the relative dimensions of the buccal *cavity* and of the oral *orifice* for some of the principal of these; the number 5 expressing the largest size, and the others in like proportion:—

Vowel.	Sound.	Size of oral opening.	Size of buccal cavity.
a	as in *ah*	5	5
a	as in *name*	4	2
e	as in *theme*	3	1
o	as in *cold*	2	4
oo	as in *cool*	1	5

These are the sounds of the five vowels, *a*, *e*, *i*, *o*, *u*, in most continental languages; and it cannot but be admitted, that the arrangement is a much more natural one than that of our own vowel series. The English *a* has three distinct sounds capable of prolongation;*—the true broad *a* of *ah*, slightly modified in *far;* the *a* of *fate*, corresponding to the *e* of French; and the *a* of *fall*, which should be really represented by *au*. This last is a simple sound, though commonly reckoned as a diphthong. In Kempelen's scale, the oral orifice required to produce it would be about 3, and the size of the buccal cavity 4.† On the other hand, the sound of the English *i* cannot, like that of a true vowel, be prolonged *ad libitum;* it is in fact a sort of diphthong, resulting from the transition from a peculiar indefinite murmur to the sound of *e*, which takes its place when we attempt to continue it. The sound *oy* or *oi*, as in *oil*, is a good example of the true diphthong; being produced by the transition from *au* to *e*. In the same manner, the diphthong *ou*, which is the same with *ow* in owl, is produced in the rapid transition from the broad *a* of *ah*, to the *oo* of cool. Much discussion has taken place as to the true character of *y*, when it commences a word, as in yet, yawl, &c.; some having maintained that it is a consonant, (for the very unsatisfactory reason that we are in the habit of employing *a* rather than *an*, when we desire to prefix the indefinite article to such words,) whilst others regard it as a peculiar vowel. A slight attention to the position of the vocal organs during its pronunciation makes it very clear, that its sound in such words really corresponds with that of the long (English) *e;* the pronunciation of the word yawl being the same as that of ēaul, when the first sound is not prolonged, but rapidly transformed into the second. The sound of the letter *w*, moreover, is really of the vowel character, being formed in the rapid transition from *oo* to the succeeding vowel; thus *wall* might be spelt *ōōall*. Many similar difficulties might be removed, and the conformity between spoken and written language might be greatly increased (so as to render far more easy the acquirement of the former from the latter), by due attention to the state of the vocal organs in the production of the simple sounds.

* The *short* vowel sounds, as *a* in fat, *e* in met, *o* in pot, &c., are not capable of prolongation.

† The mode of making a determination of this kind may here be given, for the sake of example. If the broad *a* be sounded, the mouth and fauces being opened wide, and we contract the oral orifice by degrees, at the same time slightly elevating the point of the tongue, we gradually come to the sound of *au;* by still further contracting the orifice, and again depressing the tongue, we form *oo*. On the other hand, in sounding *e*, the tongue is raised nearly to the roof of the mouth; if it be depressed, without the position of the lips being altered, *au* is given.

416. It is not very difficult to produce a tolerably good artificial imitation of the vowel sounds. This was accomplished by Kempelen, by means of an India-rubber ball, with an orifice at each end, of which the lower one was attached to a reed; by modifying the form of the ball, the different vowels could be sounded during the action of the reed. He also employed a short funnel-like tube, and obtained the different sounds by covering its wide opening to a greater or less extent. This last experiment has been repeated by Mr. Willis; who has also found that the vowel sounds might be imitated, by drawing out a long straight tube from the reed. In this experiment he arrived at a curious result:—with a tube of a certain length, the series of vowels, *i*, *e*, *a*, *o*, *u*, was obtained, by gradually drawing it out; but, if the length was increased to a certain point, a further gradual increase would produce the same sequence in an inverted order, *u*, *o*, *a*, *e*, *i*; a still further increase would produce a return to the first scale, and so on. When the pitch of the reed was high, and the pipe short, it was found that the vowels *o* and *u* could not be distinctly formed,—the proper tone being injured by the elongation of the pipe necessary to produce them; and this, Mr. Willis remarks, is exactly the case in the human voice, most singers being unable to pronounce *u* and *o* upon their highest notes.

417. The most natural primary division of the consonants is into those, which require a total stoppage of the breath at the moment previous to their being pronounced, and which, therefore, cannot be prolonged; and those in pronouncing which the interruption is partial, and which can, like the vowel sounds, be prolonged *ad libitum*. The former have received the designation of *explosive*; and the latter of *continuous*. In pronouncing the *explosive* consonants, the posterior nares are completely closed, so that the exit of air through the nose is altogether prevented; and the current may be checked in the mouth three ways,—by the approximation of the lips,—by the approximation of the point of the tongue to the front of the palate,—and by the approximation of the middle of the tongue to the arch of the palate. In the first of these modes we pronounce the letters *b*, and *p*: in the second, *d*, and *t*: in the third, the hard *g*, and *k*. The difference between *b*, *d*, and *g*, on the one hand, and *p*, *t*, and *k*,* on the other, seems to depend on this; —that in the former group the approximating surfaces are larger, and the breath is sent through them more strongly at the moment of opening, than in the latter. The *continuous* consonants may be again subdivided, according to the degree of freedom with which the air is allowed to make its exit, and the compression which it consequently experiences. 1. The first class includes those in which no passage of air through the nose, and in which the parts of the mouth by which the sound is produced are nearly approximated together, so that the compression is considerable. This is the case with *v* and *f*, which are produced by approximating the upper incisors to the lower lip, and which stand in nearly the same relation to each other as that which exists between *d* and *t*, or *b* and *p*. The sibilant sounds, *z*, and *s*, stand in nearly the same relation to each other; they are produced by the passage of air between the point of the tongue and the front of the palate, the teeth being at the same time nearly closed. The simple sound *sh* is formed by narrowing the channel between the dorsum of the tongue and the palate; the former being elevated towards the latter through a considerable part of its length. If, in sounding *s*, we raise the point of the tongue a very little, so as to touch the palate, the sound of *l* is

* For the sake of proper comparison, this letter should be sounded, not as *kay* but as *key*.

evolved; and in the same manner *d* is produced from *z*. This class also includes the *th*, which, being a perfectly simple sound, ought to be expressed by a single letter, as in Greek, instead of by two, of which the combination does not really produce any thing like it. For producing this sound, the point of the tongue is applied to the back of the incisors, or to the front of the palate, as in sounding *t*;* but, whilst there is complete contact of the tip, the air is allowed to pass out around it. There is this additional peculiarity (which the Author does not recollect to have seen noticed elsewhere)—that, during the pronunciation of *th*, there is no laryngeal voice, the sound being only whispered. 2. In the second class of continuous consonants, including the letters *m*, *n*, *l*, and *r*, the nostrils are not closed, and the air thus undergoes very little compression, even though the passage of air through the oral cavity is almost or completely checked. In pronouncing *m* and *n*, the breath passes through the nose alone; and the difference of the sound of these two letters, must be due to the variation in the form of the cavity of the mouth, which acts by resonance. The letter *m* is a labial, like *b*; and the only difference between the two is, that in the former the nasal passage is open, whilst the mouth remains closed; whilst in the latter, the nose is entirely closed, and the sound is formed at the moment of opening the mouth. The same correspondence exists between *n* and *t*, or *n* and *g* (the particular part of the tongue approximated to the palate not being of much consequence in the pronunciation of *n*); and hence it is that the transition from *n* to *t*, or from *n* to *g*, is so easy that the combinations *nt* and *ng* are found abundantly in most languages. The sound of *l* is produced by bringing the tip of the tongue into contact with the palate, and allowing the air to escape around it, at the same time that a vocal tone is generated in the larynx; it differs, therefore, from *th* in this last particular, as well as in the slight degree of the compression of the air which it involves. The sound of the letter *r* depends on an absolute vibration of the point of the tongue in a narrow current of air forced between the tongue itself and the palate. 3. The sounds of the third class are scarcely to be termed consonants, since they are merely *aspirations* caused by an increased force of breath. These are *h*, and the *ch*† of most foreign languages (the Greek χ). The first is a simple aspiration; the second, an aspiration modified by the elevation of the tongue, causing a slight obstruction to the passage of air, and an increased resonance in the back of the mouth. This sound would become either *g* or *k*, if the tongue, whilst it is being produced, were carried up to touch the palate.‡

418. These distinctions come to be of much importance, when we apply ourselves to the treatment of defects of articulation. Great as is the number of muscles employed in the production of definite vocal sounds, the number is much greater for those of articulate language; and the varieties of combination, which we are continually forming unconsciously to ourselves, would not be suspected without a minute analysis of the separate actions. Thus, in uttering the explosive sounds, we check the passage of air through the posterior nares, in the very act of articulating the letter; and yet this important movement commonly passes unobserved. We must regard the power of forming the several articulate sounds which have been adverted

* Hence it is easy to understand the substitution of *t* or *d*, for the English *th*, by foreigners.

† The English *ch* is merely a combination of *t* with *sh*; thus *chime* might be spelt *tshime*.

‡ The general classification proposed by Dr. M. Hall is here adopted, with some modification as to the details.

to, and their simple combinations, as so far resulting from intuition, that it can in general be more readily acquired by early practice than other actions of the same complexity; so that we may consider these movements as having somewhat of the same consensual character as that which has been attributed to the purely vocalizing actions (§ 412). But there is in many indviduals a deficiency of the power of rightly combining them, from which stammering and other imperfections result. Many theories regarding the nature of stammering have been proposed; and there can be little doubt that the impediment may be attributed to a great variety of exciting causes. A disordered action of the nervous centres must, however, be regarded as the proximate cause; though this may be (to use the language of Dr. M. Hall) either of *centric* or of *excentric* origin,—that is, may result from a morbid condition of the ganglionic centre, or from an undue excitement conveyed through its afferent nerves. When of centric origin (and this is probably the most general case) the phenomena of stammering and chorea have a close analogy to each other; in fact, stammering is frequently one of the modes in which the disordered condition of the nervous system in chorea manifests itself. It is in the pronunciation of the consonants of the explosive class, that the stammerer experiences the greatest difficulty. The total interruption to the breath which they occasion frequently becomes quite spasmodic; and the whole frame is thrown into the most distressing semi-convulsive movement, until relieved by expiration.* In the pronunciation of the continuous consonants of the first class, the stammerer usually prolongs them, by a spasmodic continuance of the same action; and there is, in consequence, an impeded, but not a suspended respiration. The same is the case with the *l* and *r* in the second class. In pronouncing the *m* and *n*, on the other hand, as well as the aspirates and vowels, it is sometimes observed that the stammerer prolongs the sound, by a full and exhausting expiration. In all these cases, then, it seems as if the muscular sense, resulting from each particular combination of actions, became the stimulus to the involuntary prolongation of that action. In some instances it is possible that the defect may result from malformation of the parts about the fauces, producing an abnormal stimulus of this kind in some particular positions of the organ; and such cases *may be* really benefited by an operation for the removal of these parts. But the effect of the operation is evidently for the most part upon the nervous system; and it coincides with what may be frequently observed, —that the stammering is increased under any unusual excitement, especially of the emotional kind.

419. The method proposed by Dr. Arnott for the prevention of stammering, consists in the connection of all the words by a vocal intonation, in such a manner that there never shall be an entire stoppage of the breath. It is justly remarked by Müller, however, that this plan may afford some benefit, but cannot do every thing, since the main impediment occurs in the middle of words themselves. One important remedial means, on which too much stress cannot be laid, is to study carefully the mechanism of the articulation of the difficult letters, and to practise their pronunciation repeatedly, slowly, and analytically. The patient would at first do well to practise sentences, from which the explosive consonants are omitted, and his chief difficulty, arising from the spasmodic suspension of the expiratory movement, would be thus avoided. Having mastered these, he may pass on to others in which

* By Dr. Arnott this interruption is represented as taking place in the larynx; that this is not the case, a little attention to the ordinary phenomena of voice will satisfactorily prove.

the difficult letters are sparingly introduced, and finally accustom himself to the use of ordinary language. One of the chief points to be aimed at, is to make the patient feel that he has command over his muscles of articulation; and this is best done by gradually leading him from that which he finds he *can* do, to that which he fears he cannot. The fact that stammering people are able to *sing* their words better than to *speak* them, has been usually explained on the supposition that, in singing, the glottis is kept open, so that there is less liability to spasmodic action; if, however, as here maintained, the spasmodic action is not in the larynx, but in the velum palati and the muscles of articulation, the difference must be due to the direction of the attention rather to the muscles of the larynx than to those of the mouth. Every one must have noticed how much the impediment of stammerers is increased when they are particularly anxious to speak fluently.

CHAPTER VII.

INFLUENCE OF THE NERVOUS SYSTEM ON THE ORGANIC FUNCTIONS.

420. Of the modes in which the Nervous System influences the Organic Functions, a part have been already considered. It has been shown (§ 183) that it is concerned in providing the conditions, either immediate or remote, under which alone these functions can be performed; so that, when its activity ceases, they cannot be much longer maintained. The first mode in which it operates upon them is, therefore, by producing sensible movements in the muscles or other contractile organs, which can be stimulated to action through it; and the contractions thus induced have usually an important effect upon them, which varies, however, in each individual case. Thus, the process of Nutritive Absorption, which is the very first stage in the operations of Vegetative Life, and which is accomplished in Plants by the accidental contact of the alimentary materials with the radical fibres, cannot take place in Animals, until the muscular apparatus of prehension has been set in action by the Will, that of deglutition by the Reflex Function, and that of the intestinal canal by direct stimulation,—the two former kinds of contraction being accomplished entirely through the nervous system, and the latter being influenced by it. The Circulation of Blood, again, is chiefly effected, in the higher Animals at least, by the contractions of a muscular organ of impulsion, which, though not essentially dependent upon nervous action, are nevertheless greatly influenced by it. The function of Respiration, again, cannot be maintained, even for a short time, without muscular movement, excited through the nervous system. The functions of Nutrition and Secretion are more independent of it; taking place, as in Plants, so long as the conditions are supplied by other functions, without any sensible movements being actually concerned in them. We shall presently see, however, that they are subject to a peculiar kind of nervous influence, which does not manifest itself in obvious movement, but in altered performance of the intimate processes themselves, showing itself in the character of the organized tissue or of the secreted product. The act of Excretion is, like ingestion, entirely performed by muscular movement, dependent upon nervous agency. Now wherever such movements of distant organs are

usually performed in connection with each other, there is an obvious channel for one kind of *sympathy* between them; an interesting example of this, is the contraction of the uterus which may be frequently made to occur, when that organ is in a relaxed state at the conclusion of labour, by applying suction or other irritation to the nipple.

421. Sympathetic movements of this kind may be excited either through the cerebro-spinal, or the ganglionic systems; and we shall be guided in our determination of their channel in each particular case, by the distribution of these systems respectively to the organ affected. The sympathetic movements of the Muscles of Animal life (§ 366) appear to be chiefly, if not entirely, excited through the Cerebro-spinal system; whilst those of the contractile tissues of the Viscera (§ 375) are probably excited through nerves which, though connected with the Cerebro-spinal system, act under peculiar conditions, and are commonly spoken of as forming part of the Sympathetic system. It has been shown (§ 200) that all the contractile organs, which may be excited through the Sympathetic or Visceral system of nerves, may also be made to act by stimuli applied to the roots of the Spinal nerves; but that each Cerebro-spinal fibre appears to pass through several ganglia, before being distributed to the organs which it supplies. Many speculations have been hazarded, as to the reasons why the visceral nerves are destitute of sensibility; and, at the time when the Sympathetic was supposed to be merely an offset from the Cerebro-spinal system, it was imagined that the use of the ganglia upon the roots of the spinal nerves was to "cut off sensation" from those concerned in the "vital and involuntary motions." The influence of Bichât's ingenious hypothesis,—that the Sympathetic system is complete and independent, ministering to the functions of Organic Life, as the Cerebro-spinal does to those of Animal Life—for a time caused this idea to be abandoned. Since, however, it has been anatomically proved, that a large proportion of the filaments of the visceral nerves are derived from the Spinal cord, this opinion has been revived, in a somewhat modified form.* Nevertheless the evidence in its support is somewhat vague; especially if the truth of the doctrine formerly urged,—that the Spinal Cord is not itself a centre of sensation,—be admitted. For it is only necessary to suppose that the white fibres of the Sympathetic nerve terminate in the true Spinal Cord, without proceeding to the Brain, to have an explanation of the absence of sensory endowments in the organs to which they are distributed, and of the complete removal of the muscles supplied by their motor nerves, from voluntary control. That a few fibres, of which the actions cannot be excited under ordinary circumstances, pass on to the Brain, would seem probable from the fact of the sensibility of some parts, in disease, which are totally insensible in their normal condition;—a fact in the explanation of which, the hypothesis just alluded to affords no assistance.

422. It appears, then, that it may be stated as a general proposition, that all the evident movements which can be excited, by irritation applied to one part of the body, in the contractile organs or tissues of another, are really effected through the true Spinal Cord, whether the contractile organ be a powerful muscle, or a thin and feeble layer of fibres around a blood-vessel or duct. Upon the reasons why the fibres of the Visceral nerves should be so peculiarly separated from the rest, we can at present only speculate; but it may not be considered improbable that, by their peculiar plexiform arrangement in the various ganglia through which they pass, connections

* See Dr. Alison on the Nerves of the Orbit; Edinb Phil. Trans. vol. xv., and Med Gaz vol xxviii. p. 378.

are established between remote organs, which tend to bring their actions into closer relation with each other than would otherwise be the case. The existence of such connections, for the purpose of harmonizing the several movements of the viscera which are concerned in the various and complex operations of Digestion and its attendant processes, may be inferred from the perfect conformity which exists between them, during all their different states of regular action; and still more, perhaps, from the phenomena of their disordered conditions. The study of these Sympathies is one of those departments of Physiology, in which it may be expected that much will be gained by patient and well-directed investigation.

423. The movements immediately concerned in the Organic Functions, however, are not influenced by Reflex action alone, but also by Emotional conditions of the mind. This is most obvious in regard to the Heart. Every one must have experienced the disturbance of its pulsations, consequent upon excitement of the feelings, of almost any description. But other organs probably experience similar changes, although of a less manifest character. It is well known that the Sympathetic system is largely distributed upon the trunks of the blood-vessels, accompanying them to their minutest ramifications; and it will be hereafter shown that the fibrous tissue of the walls of the arteries is probably susceptible of influence from these nerves. There can be little doubt, therefore, that they constitute the channel through which emotions operate in producing sudden distension of particular parts of the vascular system, as in blushing, erection, &c. And to the same kind of influence, more gradually exerted, we may very probably attribute the regulation of the supply of blood which passes to different secreting organs, in varying conditions of the system.

424. But the Sympathetic System does not consist of Cerebro-spinal filaments alone; nor is its influence only upon the motor or contractile tissues of the body. There is good evidence that the Nervous System has an immediate action upon the molecular changes which constitute the functions of Nutrition, Secretion, &c.; and the channel of that influence is probably to be found in that system of *grey* fibres formerly described (§ 111), which constitutes a considerable proportion of the visceral nerves, existing much more sparingly in most of the cerebro-spinal, but being abundant in the Fifth pair. There is no valid reason, however, to believe that any of the processes of Nutrition and Secretion are *dependent* upon this or any other kind of Nervous agency. These processes go on with great rapidity and energy in the Vegetable kingdom, in which nothing approaching to a Nervous System exists; and in the Animal kingdom they take place with equal vigour long before the least vestige of it appears. The Embryological researches of Dr. Barry have fully proved that in the earliest condition of fœtal life, the germ consists but of a congeries of cells, which have all originated in a single one; and from this mass, the several tissues are gradually generated, by a process which is termed in Germany *histological** transformation,—one set of cells being converted into muscular tissue, another into nervous tissue, another into mucous membrane, and so on. Now since this is the case, it is evident that all these processes of development must take place in virtue of the inherent properties of the primary tissue itself; since no nervous influence can be supposed to operate, before nerves are called into existence. Throughout the Animal body it may be observed that, the more vegetative the nature of any function, the less is it connected with the

* This term is used in contradistinction to *morphological*, which applies to the alterations in the *form* of the several parts of the embryo.

Nervous System; and all the experiments which have been regarded as proving that the organic functions are dependent upon nervous influence, are really explicable, fully as well, upon the supposition that they are capable of being affected by it, either in the way of excitement or retardation (see § 237). Moreover, there is abundant evidence that secretion may take place after the death of the general system, through the persistence of certain molecular changes, of which the essential conditions are not immediately altered; and the growth of the beard, which has also been occasionally observed, indicates that even nutrition may continue to a certain degree. In such a case the Animal body is reduced to the condition of a Plant; since the influence of the nervous system must then be entirely extinct. Upon those who maintain that nervous agency is a condition essential to those molecular actions of which nutrition and secretion consist, it is incumbent, therefore, to offer some more unexceptionable proof of their position than has yet been given; since their doctrine is opposed by so many considerations of great weight.

425. That many of the Organic Functions, however, are directly influenced by the Nervous System, is a matter which does not admit of dispute; and this influence, exerted sometimes in exciting, sometimes in checking, and sometimes in otherwise modifying them, may well be compared to that which the hand and heel of the rider have upon his horse, or the engine-driver exerts over a locomotive. It is most remarkably manifested in the result of severe injury of the nervous centres,—such as concussion of the brain, or of the solar plexus;* for this does not produce merely a suspension of the respiratory and other movements which minister to the organic functions, and hence a gradual stagnation of the latter,—but a sudden and complete cessation of the whole train of action, which cannot be attributed to any other cause, than a *positive* depressing influence of some kind, propagated through the nervous system. It will hereafter appear that in such cases even the vitality of the blood is often affected; the usual coagulation not taking place after death, so long, at least, as it remains within the vessels. A similar general depression may result from Mental Emotion, operating through the same channel; but this more commonly has rather a local action, or operates more gradually. The influence of the Nervous System is often especially exerted in giving temporary excitement to a secreting process, which need not be kept in constant activity, or of which circumstances may occasionally require an increase. This is the case, for example, in regard to the secretions connected with the process of digestion,—the Saliva, Gastric fluid, Bile, Pancreatic fluid, &c.; all of these being excited by the contact of the substances on which they act, with the surfaces on which their respective ducts open. The secretion of Milk, again, in a nursing female, may be excited by irritation of the nipple; and the determination of blood to the Mammæ during pregnancy must be due to increased action in the part, excited by the changes occurring in the uterus, which can scarcely operate otherwise than through the Nervous System. No other channel of influence can be well imagined for most of these operations, than the Sympathetic system; since the organs in question are for the most part supplied by it. There is an apparent exception, however, in the case of the salivary glands, which are supplied by the Fifth pair: but this nerve contains so many organic filaments, and is so intimately connected with the Sympa-

* The Author has no doubt that the occasional occurrence of death from blows on the epigastrium is to be attributed to this cause, in all the instances on record the stomach has contained food at the time and the effect of the blow would, therefore have been propagated to the rest of the viscera and the nerves distributed upon them

thetic, as evidently to supply (in the head) the place of a separate ganglionic system. It is by nervous influence that the mucous secretion covering the membranes is caused to be regularly formed for their protection; for it is shown by pathological facts that, when this influence is interrupted, the secretion is no longer supplied, and the membrane, losing its protection, is irritated by the air or the fluids with which it may be in contact, and passes into an inflammatory condition. This is the explanation of the fact which has been well ascertained, that the eye is liable to suppurate when the Fifth pair has been divided; and that the mucous membrane of the bladder becomes diseased in Paraplegia.

426. The influence of particular conditions of the mind in exciting various secretions, is a matter of daily experience. The flow of Saliva, for example, is stimulated by the idea of food, especially that of a savoury character. The Lachrymal secretion, again, which is continually being formed to a small extent, for the purpose of bathing the surface of the eye, is poured out in great abundance under the moderate excitement of the emotions either of joy, tenderness, or grief. It is checked, however, by violent emotions; hence in intense grief the tears do not flow. It is a well-known proof of moderated sorrow, when this takes place; tears, however, do not bring relief, as is commonly believed, but they indicate that it has been brought. Violent emotion may also suspend the salivary secretion; as is shown by the well-known test often resorted to in India for the discovery of a thief amongst the servants of a family,—that of compelling all the parties to hold a certain quantity of rice in the mouth during a few minutes,—the offender being generally distinguished by the comparative dryness of his mouthful at the end of the experiment. The influence of the emotion of love of offspring, in increasing the secretion of milk, is well known. The formation of this fluid is continually going on during the period of lactation; but it is greatly increased by the sight of the infant, or even by the thought of him, especially when associated with the idea of suckling; this gives rise to the sudden rush of blood to the gland, which is known by nurses as the *draught*, and which occasions a greatly-increased secretion. The strong desire to furnish milk, together with the irritation of the gland through the nipple, have often been effectual in producing the secretion in girls, old women, and even in men. The quantity of the gastric secretion is increased by exhilaration, at least if we may judge from the increase of the digestive powers under such circumstances. Freedom from mental anxiety favours the secretion of fat; whilst continual solicitude effectually checks the deposition. It has been stated that total despair has an equal tendency with absence of care, to produce this effect; persons left long to pine in condemned cells, without a shadow of hope, frequently becoming remarkably fat, in spite of their slender fare.* The odoriferous secretion of the skin, which is much more powerful in some individuals than in others, is increased under the influence of certain mental emotions (as fear or bashfulness), and commonly also by sexual desire. The sexual secretions themselves are strongly influenced by the condition of the mind. When it is frequently and strongly directed towards objects of passion, the secretions are increased in amount, to a degree which may cause them to be a very injurious drain on the powers of the system. On the other hand, the active employment of the mental powers on other objects has a tendency to render less active, or even to check altogether, the processes by which these are elaborated.†

* Fletcher's Physiology, Part II., *b*, p. 11.

† This is a simple physiological fact, but of high moral application. The Author

427. No secretion so evidently exhibits the influence of the depressing emotions as that of the Mammæ; but this may be partly due to the fact, that the digestive system of the Infant is a more delicate apparatus for testing the qualities of that secretion than any which the Chemist can devise; affording proof, by disorder of its function, of changes in the character of the milk, which no examination of its physical properties could detect. The following remarks on this subject are abridged from Sir A. Cooper's valuable work on the Breast. "The secretion of milk proceeds best in a *tranquil state of mind*, and with a cheerful temper; then the milk is regularly abundant, and agrees well with the child. On the contrary, a *fretful temper* lessens the quantity of milk, makes it thin and serous, and causes it to disturb the child's bowels, producing intestinal fever and much griping. *Fits of anger* produce a very irritating milk, followed by griping in the infant, with green stools. *Grief* has a great influence on lactation, and consequently upon the child. The loss of a near and dear relation, or a change of fortune, will often so much diminish the secretion of milk, as to render adventitious aid necessary for the support of the child. *Anxiety of mind* diminishes the quantity, and alters the quality of the milk. The

would say to those of his younger readers, who urge the wants of Nature as an excuse for the illicit gratification of the sexual passion, "Try the effects of close mental application to some of those ennobling pursuits to which your profession introduces you, in combination with vigorous bodily exercise (for the effects of which see § 278.), before you assert that the appetite is unrestrainable, and act upon that assertion." Nothing tends so much to increase the desire, as the continual direction of the mind towards the objects of its gratification. The following observations, which the Author believes to be strictly correct, are extracted from a valuable little work (anonymous) entitled "Be not deceived," addressed to Young Men; they are directed to those who maintain that, the married state being natural to Man, illicit intercourse is necessary for those who are prevented by circumstances from otherwise gratifying the sexual passion. "When the appetite is naturally indulged, that is, in marriage, the necessary energy is supplied by the nervous stimulus of its natural accompaniment of love before referred to, which prevents the injury which would otherwise arise from the increased expenditure of animal power; and in like manner also, the function being in itself grateful, this personal attachment performs the further necessary office of preventing immoderate indulgence, by dividing the attention, through the numerous other sources of sympathy and enjoyment which it simultaneously opens to the mind. But, when the appetite is irregularly indulged, that is in fornication, for want of the healthful vigour of true love, its energies become exhausted; and from the want of the numerous other sympathetic sources of enjoyment in true love, in similar thoughts, common pursuits, and above all in common holy hopes, the mere gross animal gratification of lust is resorted to with unnatural frequency, and thus its powers become still further exhausted, and, therefore, still more unsatisfying, while, at the same time, a habit is thus created, and these jointly cause an increased craving; and the still greater deficiency in the satisfaction experienced in its indulgence further, continually, ever in a circle, increases—the habit, demand, indulgence, consequent exhaustion, diminished satisfaction, and again demand, till the mind and body alike become disorganized." Such considerations as these may, to some persons, appear misplaced in a Physiological Treatise,—yet the Author feels sure that, by his well-judging readers, he will not be blamed for adverting to this subject, or for the introduction of the above quotation from a writer of whom he has no personal knowledge, but whose object must be confessed by all to be laudable. There seems to be something in the process of training young men for the Medical Profession, which encourages in them a laxity of thought and expression on these matters, that generally ends in a laxity of action and of principle. It might have been expected that those who are so continually witnessing the melancholy consequences of the violation of the Divine law in this particular, would be the last to break it themselves: but this is unfortunately very far from being the case. The Author regrets to be obliged further to remark, that some recent works which have issued from the Medical press, contain much that is calculated to excite, rather than to repress, the propensity; and that the advice sometimes given by practitioners to their patients is immoral as well as unscientific.

reception of a letter which leaves the mind in anxious suspense, lessens the draught, and the breast becomes empty. If the child be ill, and the mother is anxious respecting it, she complains to her medical attendant that she has little milk, and that her infant is griped, and has frequent green and frothy motions. *Fear* has a powerful influence on the secretion of milk. I am informed by a medical man who practises much among the poor, that the apprehension of the brutal conduct of a drunken husband, will put a stop for a time to the secretion of milk. When this happens, the breast feels knotted and hard, flaccid from the absence of milk; and that which is secreted is highly irritating, and some time elapses before a healthy secretion returns. *Terror*, which is sudden and great fear, instantly stops this secretion." Of this, two striking instances, in which the secretion, although previously abundant, was completely arrested by this emotion, are detailed by Sir. A. C. "Those passions which are generally sources of pleasure, and which, when moderately indulged, are conducive to health, will, when carried to excess, alter, and even entirely check the secretion of milk."

428. The following is perhaps the most remarkable instance on record, of the effect of strong mental excitement on the mammary secretion; the event could hardly be regarded as more than a simple coincidence, if it were not borne out by the less striking but equally decisive facts already mentioned. "A carpenter fell into a quarrel with a soldier billeted in his house, and was set upon by the latter with his drawn sword. The wife of the carpenter at first trembled from fear and terror, and then suddenly threw herself furiously between the combatants, wrested the sword from the soldier's hand, broke it in pieces, and threw it away. During the tumult, some neighbours came in and separated the men. While in this state of strong excitement, the mother took up her child from the cradle, where it lay playing, and in the most perfect state of health, never having had a moment's illness; she gave it the breast, and in so doing sealed its fate. In a few minutes the infant left off sucking, became restless, panted, and sank dead upon its mother's bosom. The physician, who was instantly called in, found the child lying in the cradle as if asleep, and with its features undisturbed; but all his resources were fruitless. It was irrecoverably gone."* In this interesting case, the milk must have undergone a change, which gave it a powerful sedative action upon the susceptible nervous system of the infant: the following, which recently occurred within the Author's own knowledge, is perhaps equally valuable to the Physiologist as an example of the similarly-fatal influence of undue emotion of a different character; and both should serve as a salutary warning to mothers, not to indulge either in the exciting or depressing passions. A lady having several children, of which none had manifested any particular tendency to cerebral disease, and

* Dr. Von Ammon, in his treatise "Die ersten Mutterpflichten und die erste Kindespflege," quoted in Dr. A. Combe's excellent little work on the Management of Infancy. Similar facts are recorded by other writers. Mr. Wardrop mentions (Lancet, No. 516), that having removed a small tumour from behind the ear of a mother, all went well until she fell into a violent passion; and the child, being suckled soon afterwards, died in convulsions. He was sent for hastily to see another child in convulsions, after taking the breast of a nurse who had just been severely reprimanded; and he was informed by Sir Richard Croft, that he had seen many similar instances. There others are recorded by Burdach (Physiologie, § 522); in one of them, the infant was seized with convulsions on the right side, and hemiplegia on the left, on sucking immediately after its mother had met with some distressing occurrence. Another case was that of a puppy, which was seized with epilepsy, on sucking its mother after a fit of rage

of which the youngest was a healthy infant a few months old, heard of the death (from acute hydrocephalus) of the infant child of a friend residing at a distance, with whom she had been on terms of close intimacy, and whose family had increased almost contemporaneously with her own. The circumstance naturally made a strong impression on her mind; and she dwelt upon it the more, perhaps, as she happened, at that period, to be separated from the rest of her family, and to be much alone with her babe. One morning, shortly after having nursed it, she laid the infant in its cradle, asleep and apparently in perfect health; her attention was shortly attracted to it by a noise; and, on going to the cradle, she found her infant in a convulsion, which lasted for a few moments and then left it dead. Now, although the influence of the mental emotion is less unequivocally displayed in this case than in the last, it can scarcely be a matter of doubt; since it is natural that no feeling should be stronger in the mother's mind under such circumstances, than the fear that her own beloved child should be taken from her, as that of her friend had been; and it is probable that she had been particularly dwelling on it at the time of nursing the infant on that morning.*

429. Other secretions are in like manner vitiated by mental emotions, although the influence is not always so manifest. Thus, the halitus from the lungs is sometimes almost instantaneously affected by bad news, so as to produce fœtid breath. A copious secretion of fœtid gas sometimes takes place in the intestinal canal, under the influence of any disturbing emotion; or the usual fluid secretions from its walls are similarly disordered. The tendency to defecation which is commonly excited under such circumstances, is not, therefore, due simply to the relaxation of the sphincter ani (as commonly supposed), but is partly dependent on the unusually stimulating character of the fæces themselves. The same may be said of the tendency to void the urine, which is experienced under similar conditions; the change in its character becomes perceptible enough among many animals, in which it acquires a powerfully disagreeable odour under the influence of fear, and thus answers the purpose which is effected in others by a peculiar secretion. It is a prevalent, and perhaps not an ill-founded opinion, that melancholy and jealousy have a tendency to increase the quantity, and to vitiate the quality, of the biliary fluid; perhaps the disorder of the organic function is more commonly the source of the former emotion than its consequence; but it is certain that the indulgence of these feelings has a decidedly morbific effect, by disordering the digestive processes, and thus reacts upon the nervous system by impairing its healthy nutrition. On the influence of mental emotion in the mother on the fœtus in utero, some remarks will be offered hereafter (Chap. xiv.).

* Another instance, in which the maternal influence was less certain, but in which it was not improbably the immediate cause of the fatal termination, occurred in a family nearly related to the Author's. The mother had lost several children in early infancy, from a convulsive disorder: one infant, however, survived the usually fatal period, and whilst nursing him, one morning, she had been strongly dwelling on the fear of losing him also, although he appeared a very healthy child. In a few minutes after the infant had been transferred into the arms of the nurse, and whilst she was urging her mistress to take a more cheerful view, directing her attention to his thriving appearance, he was seized with a convulsion-fit, and died almost instantly. Now although there was here unquestionably a predisposing cause, of which there is no evidence in the other cases, it can scarcely be doubted that the exciting cause of the fatal disorder is to be referred to the mother's anxiety. This case offers a valuable suggestion,—which, indeed, would be afforded by other considerations,—that an infant, under such circumstances, should not be nursed by its mother, but by another woman of placid temperament, who had reared healthy children of her own.

CHAPTER VIII.

ON DIGESTION AND ABSORPTION.

430. The introduction of alimentary matter into the system is accomplished in Animals by the reception of the food into an internal cavity, where it is subjected to a preparatory process, to which nothing analogous exists in Plants, and which is termed Digestion. This process may be said to have three different purposes in view;—the reduction of the alimentary matter to a fluid form, so as to become capable of absorption;—the separation of that portion of it which is fit to be assimilated, or converted into organized texture, from that which cannot serve this purpose, and which is at once rejected;—and the alteration of the chemical constitution of the former, which prepares it for the important changes which it is subsequently to undergo. The simplest conditions requisite for the accomplishment of these purposes are the following;—a fluid capable of performing the solution, and effecting the required chemical changes;—a fluid capable of separating the unorganizable matter, by a process analogous to chemical precipitation;—and a cavity or sac, in which these operations may be performed. In the lowest Animals we find this cavity formed on a very simple plan, being evidently nothing else than an inversion of the external integument, communicating with the exterior by one orifice only, through which the food is drawn in, and the excrementitious matter rejected. The fluid necessary to dissolve the food, which is known by the name of the gastric fluid or juice, and that required to separate the portion which is to be thrown off, which is known as the bile, are secreted in the walls of the stomach. In the Sea-Anemone, which affords a very characteristic example of this type of structure, it cannot be ascertained that the very rapid solution of food which takes place in the digestive cavity is assisted by any movement of its walls. In Polypes of a higher conformation, however, the digestive cavity is provided with a second orifice; the stomach opens into an intestinal tube, through which the excrement is rejected in little pellets; and the food, before entering the true digestive cavity, is submitted to a powerful gizzard or triturating apparatus. Still the bile, like the gastric juice, is secreted in the walls of the stomach, as may be distinctly perceived in many of these animals, on account of their transparency, and the bright yellow colour of the fluid. As we ascend the animal series we find no essential change in the character of the digestive apparatus. The biliary follicles are gradually collected into a glandular mass, which is altogether removed from the walls of the stomach, and which pours its secretion into the intestinal tube, at a short distance from its commencement; the gastric juice, however, is still secreted in minute sacs imbedded in the substance of the membrane; the form and arrangement of these will be hereafter described (Chap. XII.). Several accessory glands are added, the uses of which are not accurately known; and particular modifications of the apparatus are adapted to peculiarities in the nature of the food, or in the mode of its ingestion. As a general rule it may be stated that the digestive apparatus is most simple in carnivorous animals, in which it has to effect little change upon the aliment, except

solution, in order to bring it to the state fit for absorption; whilst it is most complex in those that feed upon vegetable matter, which needs to undergo a greater change, both in its chemical composition and in the mechanical arrangement of its components, before it can be rendered subservient to animal nutrition.

431. From the structure of the whole digestive apparatus of Man, and especially from the conformation of his teeth, there can be no doubt that he was intended, like the animals to which he bears the strongest zoological resemblance, to be omnivorous,—that is, to obtain sustenance from almost any kind of organized matter. Experience teaches that this is the case,—an exclusively animal and an exclusively vegetable diet being found, under the circumstances best adapted for each, to be equally conducive to the maintenance of health. The former succeeds best in cold climates, the latter in warm. The nearly universal tendency of mankind, however, to prefer a mixed diet, appears to indicate, that it was this to which Man was destined by his Creator; and it is quite certain that the most perfect physical development, and the greatest intellectual vigour, are to be found amongst those races in which this diet is the prevalent habit. A certain mixture of the proximate principles of which the body is composed, is indeed essential to health; thus it has been ascertained by experiment that neither sugar nor gum, which are the principles that constitute the *pabulum* of vegetables, nor albumen nor gelatin, which hold a corresponding rank in the animal economy, are by themselves capable of supporting health for any long time together; and an animal fed with either of the two former substances, which contain no azote, is certain to perish, if the experiment be sufficiently prolonged. A very small amount, however, of the principle termed osmazome (which is that on which the flavour of meat depends) appears to render gelatin capable of supporting health for an unlimited period. We see, therefore, that the bodily constitution requires a certain admixture of different kinds of aliment; and it has been well remarked by Dr. Prout that the *milk*, which is the earliest food destined by Nature for the young Mammiferous animal, may be taken as a type of the combination which is best adapted to its subsequent wants. The chief substances composing this fluid belong to three different groups of *staminal principles;* which, under some form, ought to be combined in the ordinary diet of Man. These are the *saccharine*, the *oleaginous*, and the *albuminous*. The *saccharine* group of principles includes nearly all those furnished by the Vegetable kingdom,—such as gum, sugar, starch, &c., which are all closely allied to sugar in their chemical composition, consisting of carbon in union with the elements of water. The *oleaginous* principles are furnished both by vegetables and animals; there is a great similarity of aspect amongst all of them; and they closely agree in chemical composition, being composed of olefiant gas and the elements of water, or of some analogous combination. The *albuminous* principles are furnished solely by animals, and contain a large proportion of azote. This group includes, along with albumen which may be regarded as most characteristic of it, gelatin and fibrin; the former of which may be considered as in some respects intermediate between albumen and the saccharine group; whilst the latter is more highly animalized than either. All these staminal principles are susceptible of transformation into new principles, according to certain laws, of which, however, our knowledge is as yet very imperfect (§ 454).

432. The first step in the process of reduction is the mastication of the food, and the impregnation of its comminuted particles with the salivary secretion. Mastication is evidently of great importance, in preparing the

substances to be afterwards operated on for the action of their solvent; and it exactly corresponds with the trituration to which the chemist would submit any solid matter, that he might present it in the most advantageous form to digestive menstruum. The complete disintegration of the alimentary matter, therefore, is of great consequence; and, if imperfectly effected, the subsequent processes are liable to derangement. This derangement we continually meet with; for there is not, perhaps, a more frequent source of dyspepsia (difficult digestion), than imperfect mastication, whether resulting from the haste with which the food is swallowed, or from the want of the proper instruments. The disintegration of the food by mechanical reduction is manifestly aided by insalivation; it is doubtful, however, to what degree the saliva has any chemical effect upon it. It has been ascertained that this fluid has the power of converting starch into sugar,—a conversion which does take place in the stomach; but from the experiments of Berzelius and Müller, it does not appear that the solution of other alimentary substances is more facilitated by the impregnation of them with saliva, than if pure water only had been employed. The chemical nature of the salivary secretion will be described at the same time with the structure of the gland itself (Chap. XII.).

433. When the reduction of the food in the mouth has been sufficiently accomplished, it is carried into the œsophagus by the action of deglutition. The share which the nervous system has in the action has been already stated (§ 191); and it here only remains to define more precisely the different movements which are concerned in it. These were first described in detail by Magendie; but his account requires some modification, through the more recent observations of Dzondi.* The *first* stage in the process is the carrying-back of the food, until it has passed the anterior palatine arch, by the approximation of the tongue and the palate. This is a purely voluntary movement. In the *second* stage, the tongue is carried still further backwards, and the larynx is drawn forwards under its root, so that the epiglottis is pressed down over the rima glottidis. The muscles of the anterior palatine arch contract after the morsel has passed it, and assist its passage backwards; these, with the tongue, cut off completely the communication between the fauces and the mouth. At the same time, the muscles of the posterior palatine arch contract in such a manner, as to cause the sides of the arch to approach each other like a pair of curtains; so that the passage from the fauces into the posterior nares is nearly closed by them; to the cleft between the approximated sides the uvula is applied like a valve. A sort of inclined plane, directed obliquely downwards and backwards, is thus formed; and the morsel slides along it into the pharynx, which is brought up to receive it. Some of these acts may be performed voluntarily; but the combination of the whole is instinctive. The *third* stage of the process,—the propulsion of the food down the œsophagus,—then commences. This is accomplished in the upper part by means of the constrictors of the pharynx; and in the lower by the muscular coat of the œsophagus itself. When the morsels are small, and are mixed with much fluid, the undulating movements from above downwards succeed each other very rapidly; this may be well observed in horses whilst drinking; large morsels, however, are frequently some time in making their way down. Each portion of food and drink is included in the contractile walls, which are closely applied to it during the whole of its transit. The gurgling sound which is observed when drink is poured down the throat of a person *in articulo mortis*, is

* Müller's Physiology, p. 501.

due to the want of this contraction. The whole of the third stage is completely involuntary.—The usual peristaltic movements of the œsophagus are reversed in vomiting; and this reversion has been observed, even after the separation of the stomach from the œsophagus, as a consequence of the injection of tartarized antimony into the veins. At the point where the œsophagus enters the stomach,—the cardiac orifice of the latter,—there is a sort of sphincter which is usually closed. This opens when there is a sufficient pressure on it, made by accumulated food; and afterwards closes, so as to retain the food in the stomach. The opening of the cardia is one of the first acts which takes place in vomiting. When the sphincter is paralyzed by division of the pneumogastric nerve, the food regurgitates into the œsophagus.

Action of the Stomach.

434. A remarkable opportunity of ascertaining the condition of the Stomach during digestion, has lately presented itself, in a case in which a large fistulous aperture remained after a wound that laid open the cavity, but in which the general health has been completely recovered, so that the process may be considered as normally performed.* "The inner coat of the stomach, in its natural and healthy state, is of a light or pale pink colour, varying in its hues, according to its full or empty state. It is of a soft or velvet-like appearance, and is constantly covered with a very thin, transparent, viscid mucus, lining the whole interior of the organ. By applying aliment or other irritants, to the internal coat of the stomach, and observing the effect through a magnifying glass, innumerable lucid points, and very fine nervous or vascular papillæ, can be seen arising from the villous membrane, and protruding through the mucous coat, from which distils a pure, limpid, colourless, slightly viscid fluid. The fluid thus excited is invariably distinctly acid. The mucus of the stomach is less fluid, more viscid or albuminous, semi-opaque, sometimes a little saltish, and does not possess the slightest character of acidity. The gastric fluid never appears to be accumulated in the cavity of the stomach while fasting; and is seldom, if ever, discharged from its proper secerning vessels, except when excited by the natural stimulus of the aliment, mechanical irritation of tubes, or other excitants. When aliment is received, the juice is given out in exact proportion to its requirements for solution, except when more food has been taken than is necessary for the wants of the system." That the quantity of the gastric juice secreted from the walls of the stomach depends rather upon the general requirements of the system, than upon the quantity of food introduced into the digestive cavity, is a principle of the highest practical importance, and cannot be too steadily kept in view in dietetics. A *definite proportion* only of aliment can be perfectly digested in a given quantity of the fluid; the action of which, like that of other chemical operations, ceases after having been exercised on a fixed and definite amount of matter. "When the juice has become saturated, it refuses to dissolve more; and, if an excess of food has been taken, the residue remains in the stomach, or passes into the bowels in a crude state, and becomes a source of nervous irritation, pain, and disease, for a long time." The unfavourable effect upon the stomach itself of an undue burthen of food, interferes with its healthy action; and thus the quantity really appropriate is not dissolved. The febrile disturb-

* See the case of Alexis St. Martin, with the observations and experiments of Dr. Beaumont, republished in this country by Dr. A. Combe.

ance is thus increased; and the mucous membrane of the stomach exhibits evident indications of its morbid condition. The description of these indications given by Dr. Beaumont is peculiarly graphic as well as hygienically important.

435. "In disease, or partial derangement of the healthy function, the mucous membrane presents various and essentially different appearances. In febrile conditions of the system, occasioned by whatever cause,—obstructed perspiration, undue excitement by stimulating liquors, overloading the stomach with food, fear, anger, or whatever depresses or disturbs the nervous system,—the villous coat becomes sometimes red and dry, at other times pale and moist, and loses its smooth and healthy appearance; the secretions become vitiated, greatly diminished, or even suppressed; the coat of mucus scarcely perceptible, the follicles flat and flaccid, with secretions insufficient to prevent the papillæ from irritation. There are sometimes found, on the internal coat of the stomach, eruptions of deep-red pimples, not numerous, but distributed here and there upon the villous membrane, rising above the surface of the mucous coat. These are at first sharp-pointed, and red, but frequently become filled with white purulent matter. At other times, irregular, circumscribed red patches, varying in size and extent from half an inch to an inch and a half in circumference, are found on the internal coat. These appear to be the effects of congestion in the minute blood-vessels of the stomach. There are also seen at times small aphthous crusts, in connection with these red patches. Abrasion of the lining membrane, like the rolling up of the mucus coat into small shreds or strings, leaving the papillæ bare for an indefinite space, is not an uncommon appearance. These diseased appearances, when very slight, do not always affect essentially the gastric apparatus. When considerable, and particularly when there are corresponding symptoms of disease,—as dryness of the mouth, thirst, accelerated pulse, &c.—*no gastric juice can be extracted by the alimentary stimulus.* Drinks are immediately absorbed or otherwise disposed of; but food taken in this condition of the stomach remains undigested for twenty-four or forty-eight hours, or more, increasing the derangement of the alimentary canal, and aggravating the general symptoms of disease. After excessive eating or drinking, chymification is retarded; and, though the appetite be not always impaired at first, the fluids become acrid and sharp, excoriating the edges of the aperture, and almost invariably producing aphthous patches and the other indications of a diseased state of the internal membrane. Vitiated bile is also found in the stomach under these circumstances, and flocculi of mucus are more abundant than in health. Whenever this morbid condition of the stomach occurs, with the usual accompanying symptoms of disease, there is generally a corresponding appearance of the tongue. When a healthy state of the stomach is restored, the tongue invariably becomes clean."*

* Dr. A. Combe's commentary on the above passage is too apposite to be omitted. "Many persons who obviously live too freely, protest against the fact, because they feel no immediate inconvenience, either from the quantity of food, or the stimulants in which they habitually indulge; or, in other words, because they experience no pain, sickness, or headache,—nothing, perhaps, except slight fulness and oppression, which soon go off. Observation extended over a sufficient length of time, however, shows that the conclusion drawn is entirely fallacious, and that the real amount of injury is not felt at the moment, merely because, for a wise purpose, nature has deprived us of any consciousness of either the existence or the state of the stomach during health. In accordance with this, Dr. Beaumont's experiments prove, that extensive erythematic inflammation of the mucous coat of the stomach was of frequent occurrence in St. Martin after excesses in eating, and especially in drinking,

436. In regard to the cause of the sense of Hunger, many different theories have been propounded, of which none can be admitted as entirely satisfactory; and the question must yet be considered as requiring elucidation. The following positions, however, may be considered as well ascertained.—The sense of Hunger, although referred to the stomach, is governed by the condition of the system at large; being increased, when the demand for nutrition is greater than that which the blood can supply; and being diminished, when such an addition is made to the nutritive ingredients contained in the latter, as renders it adequate for this purpose, even though this addition be not made through the introduction of food in the usual manner. It is, however, immediately dependent on some condition of the stomach itself; for it is abated, if not arrested, by section of the eighth pair of nerves (§ 199); and it may be temporarily alleviated by the introduction into its cavity of matter which is not alimentary, but which causes pressure on its walls, and probably a flow of gastric juice. It may subside instantaneously under the influence of mental emotion, or of other strong impressions on the nervous system.—It is easy to prove that many of the causes which have been assigned for it, are but little or not at all concerned in the production of the sensation. Thus, mere emptiness of the stomach does not produce it; since, if the previous meal have been sufficient, the food passes from its cavity some time before a renewal of hunger is felt. It cannot be due to the action of the gastric fluid upon the coats of the stomach themselves; since this fluid is not poured into the stomach, except when the production of it is stimulated by the irritation of its secreting follicles. By Dr. Beaumont it is thought that the distension of these follicles by the secreted fluid is the proximate cause of hunger; but there is no more reason to believe that the secretion of gastric fluid is accumulating during the intervals when it is not required, than there is in the case of saliva, the lachrymal fluid, or any other secretions which are occasionally poured out in large quantities under the influence of a particular stimulus; and, moreover, it is difficult to imagine how mental emotion, or any impression on the nervous system alone, can relieve such distension.

437. It may, perhaps, be a more probable supposition, that there is a certain condition of the capillary circulation in the stomach, which is preparatory to the secretion, and which is excited by the influence of the sympathetic nerves, that communicate (as it were) the wants of the general system. This condition may be easily imagined to be the proximate cause of the sensation of hunger, by acting on the par vagum. When food is introduced into the stomach, the act of secretion is directly excited; the capillary vessels are gradually unloaded; and the immediate cause of the impression on the par vagum is withdrawn. By the conversion of the alimentary matter into materials fit for the nutrition of the system, the remote demand is also satisfied; and thus it is that the condition of the stomach just referred to, is permanently relieved by the ingestion of substances that can serve as food. But if the ingested matter be not of a kind capable of solution and assimilation, the feeling of hunger is only temporarily relieved, and soon returns in greater force than before. The theory here given

even when no marked general symptom was present to indicate its existence. Occasionally, febrile heat, nausea, headache, and thirst were complained of, but not always. Had St. Martin's stomach, and its inflamed patches, not been visible to the eye, he too might have been pleased that his temporary excesses did him no harm; but, when they presented themselves in such legible characters, that Dr. Beaumont could not miss seeing them, argument and supposition were at an end, and the broad fact could not be denied."

seems reconcilable with all that has been said of the conditions of the sense of hunger; and particularly with what is known of the influence produced upon it by nervous impressions, which have a peculiar influence upon the capillary circulation. It also corresponds exactly with what we know of the influence of the nervous system and of mental impressions upon other secretions, (§ 426).

438. The sense of Hunger, like other sensations, may not be taken cognizance of by the mind, if its attention be strongly directed towards other objects; of this fact almost every one engaged in active occupations, whether mental or bodily, is occasionally conscious. The nocturnal student, who takes a light and early evening meal, and, after devoting himself to his pursuits for several hours uninterruptedly, retires to rest with a wearied head and an empty stomach, but without the least sensation of hunger, is frequently prevented from sleeping by an indescribable feeling of restlessness and *deficiency;* and the introduction of a small quantity of food into the stomach will almost instantaneously allay this, and procure comfortable rest. Many persons, again, who desire to take active exercise before breakfast, are prevented from doing so by the lassitude and even faintness which it induces,—the bodily exercise increasing the demand for food, whilst it draws off the attention from the sensation of hunger. The Author may be excused for mentioning the following circumstance which some years ago occurred to himself, and which seems to him a good illustration of the principle, that the sense of hunger *originates* in the condition of the general system, and that its *manifestation* through a peculiar action in the stomach, is to be regarded as a secondary phenomenon, adapted, under ordinary circumstances, to arouse the mind to the actions necessary for the supply of the physical wants. He was walking alone through a beautiful country, and with much to occupy his mind; and, having expected to meet with some opportunity of obtaining refreshment on his road, he had taken no food since his breakfast. This expectation, however, was not fulfilled; but, as he felt no hunger, he thought little of the disappointment. It was evening before he approached the place of his destination, after having walked about twenty miles, resting frequently by the way; and he then began to feel a peculiar lassitude, different from ordinary fatigue, which rapidly increased, so that during the last mile he could scarcely support himself. "The stimulus of necessity," however, kept him up; but on arriving at his temporary home, he immediately fainted. It is obvious that, in this case, the occupation of the mind on the objects around, and on its own thoughts, had prevented the usual warning of hunger from being perceived; and the effect which succeeded was exactly what was to be anticipated, from the exhaustion of the supply of food occasioned by the active and prolonged exertion.

439. The conditions of the sense of Thirst appear to be very analogous to those of hunger. This sense is not referred, however, to the stomach, but to the fauces. It is generally considered that it immediately results from an impression on the nerves of the stomach; since, if liquids are introduced into the stomach through an œsophagus tube, they are just as effectual in allaying thirst, as if they are swallowed in the ordinary manner. It may, however, be doubted whether the sense of thirst is not even more immedietely connected with the state of the general system than that of hunger; for the immediate relief afforded by the introduction of fluid into the stomach is fully accounted for, by the instantaneous absorption of the fluid into the veins, which is known to take place, when there is a demand for it, not only from Dr. Beaumont's observations, but from many experi-

ments made with reference to this particular question. This demand is increased with almost equal rapidity by any excess in the amount of the fluid excretions; and it may be satisfied without the introduction of water into the stomach* (§ 461). Thirst may also be produced, however, by the impression made by peculiar kinds of food or drink upon the walls of the alimentary canal; thus salted or highly-spiced meat, fermented liquors when too little diluted, and other similarly irritating agents, excite thirst; the purpose of which is obviously to cause ingestion of fluid by which they may be diluted.

440. The food which is propelled along the œsophagus, enters the stomach through its cardiac orifice, in successive waves; and it is immediately subjected to a peculiar peristaltic movement, which has for its object to produce the thorough intermixture of the gastric fluid with the alimentary mass, and also to aid the solution of the latter by the gentle trituration to which it is thus subjected. The muscular fasciculi composing the human stomach are so disposed as to shorten its diameter in every direction; and by the alternate contraction and relaxation of these bands, a great variety of motions is induced in this organ, sometimes transversely, and at other times longitudinally. "These motions," Dr. Beaumont remarks, "not only produce a constant disturbance or *churning* of the contents of the stomach, but they compel them, at the same time, to revolve about the interior from point to point, and from one extremity to the other." In addition to these movements, there is a constant agitation of the stomach, produced by the respiratory muscles. The motions of the stomach itself are not performed on any very exact plan, and are much influenced by the character of the ingesta, the state of the general system, and by other circumstances. The following is the ordinary course, however, of the revolutions of the food. "After passing the œsophageal ring, it moves from right to left, along the small arch; thence, through the large curvature, from left to right. The bolus, as it enters the cardia, turns to the left, passes the aperture,† descends into the splenic extremity, and follows the great curvature towards the pyloric end. It then returns, in the course of the smaller curvature, makes its appearance again at the aperture in its descent into the great curvature, to perform similar revolutions. These revolutions are completed in from one to three minutes. They are probably induced in a great measure, by the circular or transverse muscles of the stomach. They are slower at first than after chymification has considerably advanced," at which time also there is an increased impulse towards the pylorus. It is probable that, from the very commencement of chymification, until the organ becomes empty, portions of chyme are continually passing into the duodenum; for the bulk of the alimentary mass progressively diminishes, and this the more rapidly as the process is nearer its completion.

441. The accelerated expulsion appears to be effected by a peculiar action of the transverse muscles, and especially of that portion of them which surrounds the stomach at about four inches from its pyloric extremity. This band is so forcibly contracted in the latter part of the digestive process, that it almost separates the two portions of the stomach, into a sort of hour-glass form; and Dr. B. states that, when he attempted to introduce a long thermometer tube into the pyloric portion of the stomach, the bulb was at first gently resisted, then allowed to pass, and then grasped by the

* This was among the remarkable results of the injection of fluid into the veins, in the Asiatic Cholera.

† The fistulous orifice in St. Martin's stomach, through which these observations were made.

muscular parietes beyond, so as to be drawn in; whence it is evident that the contraction has for its object to resist the passage of solid bodies into the pyloric extremity of the stomach, at this stage of digestion, whilst the matter which has been reduced to the fluid form is pumped away (as it were) by the action of that portion of the viscus. These peculiar motions continue until the stomach is perfectly empty, and not a particle of food or chyme remains. Of the degree in which they are dependent upon the influence of the nervous system, some idea has been already given (§ 235); there is yet much to be learned, however, especially in regard to the degree in which the movements may be checked or altered by impressions transmitted through the nervous system. It is stated by Brachet that, in some of his experiments upon the par vagum, some hours after section of the nerve on both sides, the surface only of the alimentary mass was found to have undergone solution, the remainder of the mass remaining in the condition in which it was first ingested; and if this statement can be relied on, it would appear that the movements of the stomach, like those of the heart, can be readily affected by a strong nervous impression. It may be partly in this manner, therefore, and not by acting upon the secretions alone, that strong emotions influence the process, as they are well known to do. On the other hand, the moderate excitement of pleasurable emotions may be favourable to the operation, not only by giving firmness and regularity to the action of the heart, and thence promoting the circulation of the blood and the increase of the gastric secretion, but also in imparting firmness and regularity to the muscular contractions of the stomach.

Action of the Intestinal Tube.

442. The pulpy substance to which the aliment is reduced, by the mechanical reduction and chemical solution it has undergone in the mouth and stomach, is termed *chyme*. The consistency of this will of course vary in some degree with the quantity of fluid ingested; in general it is greyish, semifluid, and homogeneous; and possesses a slightly acid taste, but is otherwise insipid. Dr. Beaumont describes it as varying in its aspect, from that of cream, which it presents when the food has been of a rich character, to that of gruel, which it possesses when the diet has been farinaceous. The passage of the chyme through the pyloric orifice is at first slow; but when the digestive process is nearly completed, it is transmitted in much larger quantities. From the time that the ingested matter enters the intestinal canal, it is propelled by the simple peristaltic action of its muscular coat, which is directly excited by the contact either of this matter, or of the secretions which are mingled with it;* and all that is not absorbed is thus conducted to the rectum, its expulsion from which is due to an action of a strictly reflex kind, excited through the nervous centres (§ 202). During its progress through the intestinal tube, the product of the gastric operation undergoes very important changes. The chyme is mingled in the duodenum with the biliary and pancreatic secretions, which effect an immediate alteration both in its sensible and chemical properties. The nature of this alteration can be best estimated, by mingling bile with chyme removed from the body. This has been done by several experimenters on the lower animals; and by Dr. Beaumont in the case already referred to,

* The bile seems to have an important share in producing this effect; since, when the ductus choledochus is tied, constipation always occurs. The action of mercury as a purgative appears to take place through the increase of the hepatic and other secretions which it induces.

which afforded him the means of obtaining not only chyme, but bile and pancreatic fluid. The effect of this admixture was to separate the chyme into three distinct parts,—a reddish brown sediment at the bottom,—a whey-coloured fluid in the centre,—and a creamy pellicle at the top. The central portion is probably that which is absorbed as *chyle;* the sediment, partly consisting of the insoluble portion of the food, and partly of the biliary matter itself, is evidently excrementitious; the creamy or oily portion is probably taken up by the lacteals, and appears as fatty matter in the fluid drawn from them. It is not until the food has passed the orifice of the ductus choledochus, that the process of nutritive absorption begins,—the lacteals not being distributed upon the stomach or the higher part of the duodenum.

443. By the gradual withdrawal of their fluid portion, the contents of the alimentary canal are converted into a mass of greater consistence; and this, as it advances through the small intestines, assumes more and more of a fæcal character. A part of the fæces, however, may be derived from the secretions of the enteritic mucous membrane itself; but there is no distinct evidence that these consist, in the ordinary state, of any thing else than mucus; since the substances found on the inner surface of the intestines of animals that have been long kept fasting, bear evident traces of intermixture with the biliary and pancreatic secretions. There can be no doubt, however, that a large quantity of fluid is poured out by the follicles of the enteritic mucous membrane, when they are in a state of irritation from disease, or from the stimulus of a purgative medicine; since the amount of water discharged from the bowels is often much greater than that which has been ingested, and must be derived from the blood. The secretion of the cœcum has been ascertained to be, in herbivorous animals, distinctly acid during digestion; and there is reason to believe that the food there undergoes a second process analogous to that to which it has been submitted in the stomach, and fitted to extract from it whatever undissolved alimentary matter it may still contain. There is no evidence, however, that this is the case in Man, whose cœcum is very small compared to that of most herbivorous animals.

Nature of Chymification.

444. The causes of the reduction of the food in the stomach have long been a fruitful source of discussion amongst physiologists; and various hypotheses have been devised to account for it. Some have compared the stomach of Man to the gizzard of a fowl, and have supposed that the *trituration* of the food between its walls was the essential element in the process; but this doctrine is completely incompatible with the fact, that digestible substances inclosed in metallic balls with perforations in their sides are still dissolved by the power of the gastric fluid, though the walls of the stomach do not come in contact with them. Others, again, have imagined that the process of digestion is one of *putrefaction;* but this idea, putting aside its inherent absurdity, is proved to be incorrect by the fact, that the gastric juice has a decidedly antiseptic quality. Others, in despair of obtaining any other solution, have attributed the operation to the direct agency of the *vital principle;* forgetting that, as long as the aliment remains within the stomach and intestinal canal, it can no more be the subject of any peculiarly vital process, than if it were in contact with the skin, of which the mucous membrane is but an internal reflection. The theory of *chemical solution,* which was at first regarded by many as quite untenable, has been of late

years so much strengthened by new facts and arguments, that there now appears no valid reason for withholding our assent from it; even though it cannot yet give a complete explanation of the complex phenomena in question. The chief opposition to this theory has arisen from the difficulty of imagining, that any simply chemical solvent should have the power of acting on so great a variety of substances, and of reducing them to a state so homogeneous. This difficulty, however, seems now, in a great degree, removed, by the discovery of the close chemical relation that subsists between the various substances of each of the groups already enumerated (§ 431); which renders it easy to conceive, that the changes involved in their reduction may be of a very simple character.

445. The first series of facts which will be here adduced, as throwing light on the process of chymification, is that which has been obtained by the experiments of Dr. Beaumont upon the individual already alluded to. (§ 434). By introducing a tube of India-rubber into the empty stomach, he was able to obtain a supply of gastric juice whenever he desired it; for the tube served the purpose of stimulating the follicles to pour forth their secretion, and at the same time conveyed it away. This fluid, of which the existence has been denied by some physiologists, is not very unlike saliva in its appearance; it is, however, distinctly acid to the taste; and chemical analysis shows that it contains a considerable proportion of free muriatic acid, and also some acetic acid. The former must evidently be derived from the decomposition of the muriate of soda contained in the blood, the remote source of which is the salt ingested with the food. The latter is an organic compound, probably formed at the expense of some of the saccharine matter of the previous aliment. Of equal importance with the free acids, is an animal matter, soluble in cold water, but insoluble in hot, bearing considerable resemblance to albumen. Of this more will be said hereafter. Besides these principal ingredients, the gastric fluid contains muriates and phosphates of potass, soda, magnesia, and lime. It possesses the power of coagulating albumen in an eminent degree; it is powerfully antiseptic, checking the putrefaction of meat; and it is effectually restorative of healthy action, when applied to old fœtid sores and foul ulcerating surfaces. It may be kept for many months, if excluded from the air, without becoming fœtid.

446. The gastric juice obtained from the stomach, was found by Dr, Beaumont to possess the power of dissolving various kinds of alimentary substances, when these were submitted to its action at a constant temperature of 100° (which is about that of the stomach), and were frequently agitated. The solution appeared to be in all respects as perfect as that which naturally takes place in the stomach; but required a longer time. This is readily accounted for when we remember, that no ordinary agitation can produce the same effect with the curious movements of the stomach; and that the continual removal, from its cavity, of the matter which has been already dissolved, must aid the operation of the solvent on the remainder. The following is one out of many experiments detailed by Dr. Beaumont. "At 11½ o'clock, A. M., after having kept the lad fasting for 17 hours, I introduced a gum-elastic tube, and drew off one ounce of pure gastric liquor, unmixed with any other matter, except a small proportion of mucus, into a three-ounce vial. I then took a solid piece of boiled recently-salted beef, weighing three drachms, and put it into the liquor in the vial; corked the vial tight, and placed it in a saucepan filled with water, raised to the temperature of 100°, and kept at that point on a nicely regulated sand-bath. In *forty* minutes, digestion had distinctly commenced over the surface of the meat.

In *fifty* minutes, the fluid had become quite opaque and cloudy; the external texture began to separate and become loose. In *sixty* minutes, chyme began to form. At 1 o'clock, P. M., (digestion having progressed with the same regularity as in the last half-hour), the cellular texture seemed to be entirely destroyed, leaving the muscular fibres loose and unconnected, floating about in fine small shreds, very tender and soft. At 3 o'clock, the muscular fibres had diminished one-half, since the last examination. At 5 o'clock, they were nearly all digested; a few fibres only remaining. At 7 o'clock, the muscular texture was completely broken down, and only a few of the small fibres could be seen floating in the fluid. At 9 o'clock, every part of the meat was completely digested. The gastric juice, when taken from the stomach, was as clear and transparent as water. The mixture in the vial was now about the colour of whey. After standing at rest a few minutes, a fine sediment of the colour of the meat, subsided to the bottom of the vial. A piece of beef, exactly similar to that placed in the vial, was introduced into the stomach, through the aperture, at the same time. At 12 o'clock it was withdrawn, and found to be as little affected by digestion as that in the vial; there was little or no difference in their appearance. It was returned to the stomach; and, on the string being drawn out at 1 o'clock, P. M., the meat was found to be all completely digested and gone. The effect of the gastric juice on the piece of meat suspended in the stomach, was exactly similar to that in the vial, only more rapid after the first half-hour, and sooner completed. Digestion commenced on, and was confined to, the surface entirely in both situations. Agitation accelerated the solution in the vial, by removing the coat that was digested on the surface, enveloping the remainder of the meat in the gastric fluid, and giving this fluid access to the undigested portions."*

447. Many variations were made in other experiments, some of which strikingly displayed the effects of thorough mastication in aiding both natural and artificial digestion. The following table exhibits some of the most interesting results of these experiments. It may also be regarded as affording some approximation to the relative digestibility of different kinds of aliment; but a more accurate series of experiments, conducted with an express view to the determination of the quantity of albumen formed in each case, is still required for this purpose. The proportion of gastric juice to aliment, in artificial digestion, was generally calculated at one ounce of the former to one drachm of the latter. In several of the experiments, the limited extent of the powers of the solvent was very evident; its character thus corresponding exactly with that of ordinary chemical agents.

Mean Time of Chymification.

Articles of Diet.	In Stomach		In Vials	
	Preparation	H. M.	Preparation	H. M.
Beef, with salt only	Boiled	2. 45	Boiled	9. 30
Beef-steak	Broiled	3. 0	Masticated	8. 15
Beef, fresh, lean, dry	Roasted	3. 30	Roasted	7. 45
Beef, old, hard, salted	Boiled	4. 15		

* Experiments 2 and 3, of First Series.

Mutton, fresh	Broiled	3. 0	Masticated	6. 45
Ditto, ditto	Boiled	3. 0		
Ditto, ditto	Roasted	[illegible] 15		
Lamb, fresh	Broiled	2. 30		
Venison steak	Broiled	1. 35		
Pork, recently salted	Raw	3. 0	Raw	8. 30
Ditto, ditto	Fried	4. 15		
Ditto, ditto	Boiled	4. 30	Masticated	6. 30
Pork, fat and lean	Roasted	[illegible] 15		
Pig, sucking	Roasted	2. 30		
Veal, fresh	Broiled	4. 0		
Ditto, ditto	Fried	4. 30		
Liver, beef's, fresh	Broiled	2. 0	Cut fine	6. 30
Heart, animal	Fried	4. 0	Entire piece	13. 30
Brains, animal	Boiled	1. 45	Boiled	4. 30
Pig's feet, soused	Boiled	1. 0		
Tripe, soused	Boiled	1. 0		
Eggs, whipped	Raw	1. 30	Whipped	4. 0
Eggs, fresh	Raw	2. 0	Raw	4. 15
Ditto, ditto	Soft boiled	3. 0	Soft boiled	6. 13
Ditto, ditto	Hard boiled	3. 30	Hard boiled	8. 0
Ditto, ditto	Roasted	2. 15		
Ditto, ditto	Fried	3. 30		
Turkey, wild	Roasted	2. 18		
Turkey, domestic	Roasted	2. 30		
Goose, wild	Roasted	2. 30		
Ducks, domestic	Roasted	4. 0		
Fowls, domestic	Boiled	4. 0		
Ditto, ditto	Roasted	4. 0		
Ducks, wild	Roasted	4. 30		
Trout, salmon, fresh	Boiled	1. 30	Boiled	3. 30
Cod-fish, cured, dry	Boiled	2. 0	Boiled	5. 0
Salmon, salted	Boiled	4. 0	Boiled	7. 45
Oysters, fresh	Raw	2. 55	Raw, entire	7. 30
Ditto, ditto	Stewed	3. 30	Stewed	8. 25
Sago,	Boiled	1. 45	Boiled	3. 15
Tapioca	Boiled	2. 0	Boiled	3. 20
Cabbage, with vinegar	Raw	2. 0	Shaved	10. 15
Ditto, ditto	Boiled	4. 30	Boiled	20. 0
[illegible]	Boiled	2. 30		
Parsnips	Boiled	2. 30	Mashed	6. 45
Potatoes	Roasted	2. 30		
Bread, wheat, fresh	Baked	3. 30	Masticated	4. 30
Potatoes	Boiled	3. 30	Mashed	8. 30
Chicken-soup	Boiled	[illegible] 0		
Soup, beef, vegetables, and bread	Boiled	4. 0		
Gelatine	Boiled	2. 30	Boiled	4. 45
Milk	Boiled	2. 0	Boiled	4. 15
Cheese, old, strong	Raw	[illegible] 30	Masticated	7. 15
Suet, mutton, boiled	Boiled	4. 30	Divided	10. 0

448. That the foregoing table can only be regarded as approximative, is shown by the fact substantiated by Dr. Beaumont, that the rapidity of digestion varies greatly according to the quantity eaten, the nature and amount of the previous exercise, the interval since the preceding meal, the state of health and of the weather, and the condition of the mind. In scarcely any of the experiments have these circumstances been carefully noted; and, as Dr. B. himself remarks, "the only way of ensuring minuteness and accuracy as to the relative digestibility of different kinds of diet, would be to try the effect of the gastric juice, in a series of experiments, first on one article of diet, and then on another, repeating and adapting them to meet all the various conditions of the stomach, and the vicissitudes and irregularities of the system, until the whole range should be completed,—a Herculean task, which it would take years to accomplish." Some important inferences, however, may be drawn from the foregoing results. It seems to be a general rule, that the flesh of wild animals is more easy of digestion than that of the domesticated races which approach them most nearly. This may, perhaps, be partly attributed to the small quantity of fatty matter that is mixed up with the flesh of the former, whilst that of the latter is largely pervaded by it. For it appears from Dr. B.'s experiments, that the presence in the stomach of any substance which is difficult of digestion, interferes with the solution of food that would otherwise soon be reduced. It seems that, on the whole, Beef is more speedily reduced than Mutton, and Mutton sooner than either Veal or Pork. Fowls are far from possessing the digestibility that is ordinarily imputed to them; but Turkey is, of all kinds of flesh except Venison, the most soluble. Dr. B. has also ascertained that moderate exercise facilitates digestion, though severe and fatiguing exercise retards it. If the exercise be taken *immediately* after a *full* meal, however, it is probably rather injurious than beneficial; but if an hour be permitted to elapse, or if the quantity of food taken have been small, it is of decided benefit.

449. The presence of bile in the stomach has been regarded by some physiologists as an ordinary occurrence during digestion; but according to Dr. B. this is not the case, except in morbid conditions of the organ, or after a long perseverance in the use of fat or oily food. It is not impossible that the conversion of such food may be aided by the bile, the free alkali of which will have a chemical operation upon it. Dr. A. Combe suggests whether the circumstance of the peculiar digestibility of a piece of fat bacon in certain forms of dyspepsia, may not be accounted for by the presence of bile in the stomach in this condition. Dr. B.'s experiments further show that *bulk* is as necessary for healthy digestion, as the presence of the nutrient principle itself. This fact has been long known by experience to uncivilized nations. The Kamschatdales, for example, are in the habit of mixing earth or saw-dust with the train-oil, on which alone they are frequently reduced to live. The Veddahs or wild hunters of Ceylon, on the same principle, mingle the pounded fibres of soft and decayed wood with the honey on which they feed when meat is not to be had; and on one of them being asked the reason of the practice, he replied, "I cannot tell you, but I know that the belly must be filled." It is further shown by Dr. B., that soups and fluid diet are not more readily chymified than solid aliment, and are not alone fit for the support of the system; and this, also, is conformable to the well-known results of experience; for a dyspeptic patient will frequently reject chicken-broth, when he can retain solid food or a richer soup. Perhaps, as Dr. A. Combe remarks, the little support gained from fluid diet is due to the rapid absorption of the watery part of it, so that

the really nutritious portion is left in too soft and concentrated a state to excite the healthy action of the stomach.

450. From the foregoing statements we may conclude, that the process by which the food is dissolved in the gastric fluid is of a purely chemical nature, since it takes place out of the living body as well as in it,—allowance being made for the difference in its physical condition. That the natural process of digestion is imitated, when the food is submitted to the action of the gastric juice in a vial, not only in regard to the disintegration of its particles, but as to the change of character which they are made to undergo, is proved by the fact, that the artificial chyme thus formed exhibits the same changes as the real chyme, when submitted to the action of the bile (§ 442). The process of digestion, however, may be freely conceded to be vital, in so far as it is dependent upon the agency of a secreted product, which vitality alone (so far at least as we at present know) can elaborate; and all for which it is here contended is, that, when this product is once formed, it has an agency upon the alimentary matter, which, though not yet fully understood, is conformable in all that is known of its operation, to the ordinary laws of chemistry. Thus, digestion is conformable to chemical solution,—*first*, in the assistance which both derive from the minute division of the solids submitted to it;—*secondly*, in the assistance which both derive from the successive addition of small portions of the comminuted solid to the solvent fluid, and from the thorough intermixture of the two by continual agitation;—*thirdly*, in the limitation of the quantity of food on which a given amount of gastric juice can operate, which is precisely the case with chemical solvents;—*fourthly*, in the assistance which both derive from an elevation of temperature,*—the beneficial influence of heat being only limited, in the case of digestion, by its tendency to produce decomposition of the gastric fluid;—*fifthly*, in the different action of the same solvent upon the various solids submitted to it.

451. We have now to inquire what information has been obtained, with regard to the chemical nature of the organic principle, which performs so important a part in the digestive process. It may be considered a well-established fact, that diluted acids alone have no power of chymifying alimentary substances, although capable of partially dissolving some of them; but that their presence in the gastric fluid is essential to its effectual action. Thus Müller states that, when small pieces of meat, or small cubes of coagulated white of egg, have been macerated for some time in equal quantities of much-diluted muriatic, acetic, tartaric, and oxalic acids, a precipitate or turbidity may be produced by the ordinary re-agents; but that the masses are not perceptibly changed, the cubes of coagulated white of egg preserving their angles and edges for weeks. Small pieces of meat were also placed in a solution of common salt, and submitted to the action of a powerful galvanic battery, which would set free muriatic acid, without the change being perceptibly accelerated. From the recent experiments of Eberle and Schwann, however, it appears that, although acids alone have so little power of digesting food, they act energetically when combined with mucus

* The influence of temperature is remarkably shown in some of Dr. B.'s experiments. He found that the gastric juice had scarcely any influence on the food submitted to it, when the bottle was exposed to the cold air, instead of being kept at a temperature of 100°. He observed on one occasion, that the injection of a single gill of water at 50° into the stomach, sufficed to lower its temperature upwards of 30°; and that its natural heat was not restored for more than half an hour. Hence the practice of eating ice after dinner, or even of drinking largely of cold fluids, is very prejudicial to digestion.

of the stomach.* The following is an outline of these experiments. The mucous membrane of the fourth stomach of the calf, being dissected from the other coats, and washed with cold water until it no longer gives evidence of containing a free acid, is macerated in water acidulated with muriatic acid; and after some time, the liquor being filtered is found to have the property of reducing most alimentary substances, submitted to its action at a slightly-elevated temperature, even though the membrane have been previously dried. Pieces of meat and of hard-boiled egg are softened within twelve hours; and they disappear almost entirely after twelve hours more: the fluid acquires a peculiar sourish odour, which is not, however, of a putrescent character. When the fluid is not acidulated, it is found to have no more solvent power than simple water would have. It has been ascertained by the experiments of Schwann, that the proportion of free acid remains the same at the end of the digestive process as it was at its commencement, showing that it does not enter into combination with the substances dissolved; in this respect, the part which it performs in digestion corresponds with its agency in converting starch into sugar; during which none of the acid disappears.

452. The active agent in the process appears to be an organic compound, to which the name of *pepsin* has been given. The properties of this have been recently investigated by Wasmann, who first succeeded in obtaining it in an isolated state;† his observations were made upon the mucous membrane of the stomach of the pig, which greatly resembles that of Man. When this membrane is digested in a large quantity of water at from 86° to 95°, many other matters are removed from it besides pepsin; but if this water be removed, and the digestion be continued with fresh water in the cold, very little but pepsin is then taken up. Pepsin appears to be but sparingly soluble in water; when its solution is evaporated to dryness, there remains a brown, greyish, viscid mass, with the odour of glue, and having the appearance of an extract. The solution of this in water is turbid, and still possesses a portion of the characteristic power of pepsin, but greatly reduced. When strong alcohol is added to a fresh solution of pepsin, the latter is precipitated in white flocks, which may be collected on a filter, and produce a grey compact mass when dried. Pepsin enters into chemical combination with many acids, forming compounds which still redden litmus paper; and it is when thus united with acetic and muriatic acids, that its solvent powers are the greatest. "In regard to the solvent power of pepsin for coagulated albumen, it was observed by M. Wasmann that a liquid which contains 17-10,000ths of acetate of pepsin, and 6 drops of hydrochloric acid per ounce, possesses a very sensible solvent power, so that it will dissolve a thin slice of coagulated albumen in the course of 6 or 8 hours' digestion. With 12 drops of hydrochloric acid per ounce, the white of egg is dissolved in 2 hours. A liquid which contains $\frac{1}{2}$ gr. of acetate of pepsin, and to which hydrochloric acid and white of egg are alternately added, so long as the latter dissolves, is capable of dissolving 210 grains of coagulated white of egg at a temperature between 95° and 104°. It would appear, from such experiments, that the hydrochloric acid is the true solvent, and that the action of the pepsin is limited to that of disposing the white of egg to dissolve in hydrochloric acid. The acid when alone dissolves white of egg by ebullition, just as it does under the influence of pepsin; from

* By Eberle it was stated that the acidulated mucus of *any* membrane is an efficient solvent; but this has been found by Müller and Schwann to be an error, only the mucus of the stomach possessing this property.

† Graham's Elements of Chemistry, p. 1031.

which it follows that pepsin replaces the effect of a high temperature which is not possible in the stomach. The same acid with pepsin dissolved blood, fibrin, meat and cheese; while the isolated acid dissolved only an insignificant quantity at the same temperature; but when raised to the boiling point, it dissolved nearly as much, and the part dissolved appeared to be of the same nature. The epidermis, horn, the elastic tissue (such as the fibrous membrane of arteries) do not dissolve in a dilute acid containing pepsin. M. Wasmann has remarked that the pepsin of the stomach of the pig is entirely destitute of the power to coagulate milk, although the pepsin of the stomach of the calf possesses it in a very high degree; from which he is led to suppose, that the power of the latter depends upon a particular modification of pepsin, or perhaps upon another substance accompanying it, which ceases to be formed when the young animal is no longer nourished by the milk of its mother."* Without altogether assenting to all these conclusions, we may regard them as suggesting important inquiries, the prosecution of which will almost certainly throw much light on the nature of this important function.

453. The products of the digestion of the various alimentary substances, as naturallly existing in the chyme, have not yet been made the subject of accurate examination; and, until they have been thoroughly investigated, it would be premature to assert that the products of artificial digestion are in all respects similar to them. Some curious facts have been ascertained, however, on this subject; chiefly by the inquiries of Dr. Prout. The albumen which is at first formed in the stomach differs from the principle elsewhere known under that name, in its imperfect coagulation, when acted on either by acids or by heat. This is noticed even when pure albumen has been introduced into the stomach; for it is first coagulated, and then dissolved, so as to present the same characters with the albumen formed from other substances. In this process, it appears to enter into chemical combination with a large quantity of water. "The solid and tenacious albumen is thus reduced to the *weakest* possible state,—to the delicate state as it were of infancy; in short, to a state precisely analogous to that of the weak sugars and other organic compounds, as compared with the strong and perfect varieties of the same substances."† It has been further ascertained that, if the food originally contained no matter of the albuminous type, no albumen is developed in the stomach; but that, immediately on the entrance of the semifluid mass into the duodenum, and its mixture with the bile and pancreatic fluids, albuminous and other chylous matters become distinctly perceptible. At the same time, the alkali contained in the fluid of the stomach is neutralized by the free acid of the bile; and the separation takes place between the alimentary and the excrementitious matter, as already described (§ 442). It would seem that, by the time the nutritious matter is absorbed into the lacteals, the albumen formed from articles of food belonging to the same group is *strengthened;* whilst that which is formed from substances of a different character still remains weak. This, at least, appears the direct inference from the following experiment of Dr. Prout's. He fed a dog for some time exclusively on animal matter, and another on vegetable matter, and then, having killed them, he examined the chyle of each, with the following result.

* Graham, op. cit., p. 1033.
† Dr. Prout's Bridgewater Treatise, p. 503.

	Vegetable.	*Animal.*
Fibrin	0·6	0·8
Incipient Albumen	4·6	4·7
Albumen	0·4	4·6
Oil and Sugar	trace	trace
Salts	0·8	0·7
Water	93·6	89·2
	100·0	100·0

The correspondence in the ingredients of the chyle is thus seen to be very close, except in regard to the amount of perfect albumen, which is very small in the animal whose food had been vegetable.

454. Our knowledge of the nature of the digestive process has lately received another important addition from the discovery, that the chief proximate principles of the Animal tissues, and those which have been regarded as most nutritious among vegetables, have almost identically the same chemical composition, and may be regarded as modifications of a fundamental principle, to which the name of *protein* has been given. This conformity will appear from the following comparative analyses, lately executed in the laboratory of Liebig.

	Fibrin.	Albumen.		Casein.
		Of Eggs.	Of Serum.	
Carbon	54·56	54·48	54·84	54·96
Nitrogen	15·72	15·70	15·83	15·80
Hydrogen	6·90	7·01	7·09	7·15
Oxygen, Phosphorus, Sulphur	22·82	22·81	22·24	22·09
	100·00	100·00	100·00	100·00

The proportion of carbon in all these substances is that of 8 equivalents of the latter to 1 of the former. They differ slightly in the minute quantity of phosphorus and sulphur which they contain; but agree in many other important chemical properties. Thus, they all dissolve, with the aid of heat, in concentrated muriatic acid; and the solutions, kept for a time at a pretty high temperature, first assume a beautiful lilac, and then a rich violet blue colour. At this stage of the decomposition, each of the three substances reacts in the same way with carbonate of ammonia and other reagents. The parallel Vegetable principles are vegetable fibrin (a constituent of gluten first properly distinguished by Liebig), gluten itself, vegetable albumen, and legumin; this last is termed by Liebig vegetable casein, from its holding the same relation to vegetable albumen that animal casein does to animal albumen. The following is the elementary composition of these substances:—

	Vegetable fibrin.	Gluten.	Veg. albumen.	Legumin.
Carbon	54·60	55·22	55·01	54·14
Nitrogen	15·81	15·98	15·92	15·67
Hydrogen	7·30	7·42	7·23	7·15
Oxygen, Phosphorus, Sulphur	22·28	21·38	21·84	23·03

Thus it appears that the azotized Vegetable principles may be converted into those organic compounds which have been ordinarily considered as peculiar to Animals, without any essential change in their chemical composition.

455. When albumen or fibrin is dissolved in a moderately-strong solution of caustic potass, and is heated to about 120°, the small portions of phosphorus and sulphur it contains are separated in the form of phosphate of potass and sulphuret of potassium; and when this solution is saturated with acetic acid, a gelatinous substance is precipitated, which is the same in aspect and constitution whether obtained from fibrin or albumen. To this the term *protein* has been given. After being washed, it is still gelatinous, of a grayish colour, and semi-transparent; when dried, it is yellowish, hard, easily pulverized, tasteless, insoluble in water and alcohol; and, like fibrin and albumen, it is not fusible by heat without decomposition. The formula for protein, according to Mulder, is,—40 Carbon, 31 Hydrogen, 5 Nitrogen, 12 Oxygen.* It may be obtained equally well from the globulin of blood, from the casein of milk, and from vegetable albumen; whence it is evident that these substances are all to be regarded as modifications of a common principle. The nature of these modifications may be partly understood from the fact, that protein unites, according to strictly chemical principles, with many inorganic substances; forming new compound acids when combining with acids; and acting in some degree as an acid, when brought into relation with bases, such as the oxides of lead and silver, of which one atom combines with 10 of protein. Viewed as chemical compounds, fibrin and albumen may be regarded as the products of the union with protein of definite proportions of sulphur and phosphorus. The following are their formulæ, according to Mulder.

Fibrin, and the albumen of eggs .	10 Pro. + 1 Sulph. + $\frac{1}{2}$ Phos.
Albumen of serum	10 Pro. + 2 Sulph. + $\frac{1}{2}$ Phos.

456. From these facts, taken in combination with those already mentioned, it seems scarcely possible to resist the conclusion, that the process of digestion (strictly so called) is one of a purely chemical nature. The conversion of the azotized animal and vegetable substances into albumen, can scarcely be viewed in any other light; for the change of form and of external characters is in no instance so great, as that which starch and gum undergo during their conversion into sugar, which is well known to be of a strictly chemical nature. The albumen, thus formed, is dissolved in the water that has been ingested, and in the gastric secretion; and becomes one of the most important and characteristic ingredients of chyle. The non-azotized vegetable matters, which belong to the class of *saccharine* compounds, do not seem to be so readily disposed of. That they are partially (at least) converted into albumen, appears probable from the fact, that animals may be fed upon these alone, without their nutrition being impeded; as well as from their absence or their very small proportion in the chyle. How this conversion is effected is still unexplained; by Dr. Prout† it is supposed that "under ordinary circumstances, the azote is principally furnished by a highly azotized substance (organized urea?) secreted from the blood, either into the stomach or duodenum,‡ or into both these localities;

* Liebig takes rather a different view of its composition, which is, however, equally conformable with analytic results. His formula is,—48 Carbon, 36 Hydrogen, 6 Nitrogen, 14 Oxygen.

† On Stomach and Urinary Diseases, p. xxviii. note.

‡ May this be the function of the glands of Brunner, which are situated in the duodenum and commencement of the jejunum only? W. B. C.

and that the portion of the blood thus deprived of its azote is separated from the general mass of blood by the liver, as one of the constituents of the bile; which secretion, as a whole, is remarkably deficient in azote." The saccharine principles, however, may be easily converted into those of an oleaginous character; and they are, perhaps, the chief source of the fatty matter contained in the chyle, the proportion of which is much greater than could be accounted for by the quantity of such matter that is usually ingested. The oleaginous compounds forming part of the food are probably absorbed as such, and gradually converted into other principles. It is justly remarked by Dr. Prout, that we know that such conversion may take place, from the circumstance that the life of an animal may be prolonged by the appropriation of the oleaginous and other matters contained within its own body.—Here, then, we quit for the present the account of the chemical changes, which form part of the process of assimilation. The alimentary matter, once introduced into the vessels, undergoes a series of most important alterations, both before and after it enters the circulating system, which altogether constitute the function of Nutrition; and it will be convenient to describe these altogether under that head.

457. A general review of the facts now stated will lead us to the following conclusions. 1. That, by the operation of the gastric fluid, the azotized principles of the food, whether animal or vegetable, are dissolved in the stomach, and are converted into albumen. 2. That the saccharine principles undergo a further change in the duodenum, by which they are partly converted into albumen, and partly into oleaginous matter; and that they are absorbed by the lacteals of the intestines in one of these two states. 3. That the oleaginous principles are either converted into albumen, or are absorbed without alteration. 4. That (with the exception of certain mineral substances) matters which cannot be reduced to either of these forms, are rejected as excrementitious.

Lacteal and Lymphatic Absorption.

458. Although there can be no doubt that the Mucous membrane is capable of absorbing by its whole surface, it can scarcely be questioned that this function is most energetically performed by the *villi* which cover it. These are short processes, from a quarter of a line to a line and a half in length; giving to the membrane, where they are most numerous, a fleecy appearance. In Man they are commonly cylindrical or nearly so; but in many of the lower animals they are spread out into broader laminæ at their base, and are connected together so as to form ridges or folds. It was formerly believed that the villi were not supplied with blood-vessels. So far is this from being the case, however, that in each villus there is a minute plexus of blood-vessels, of which the larger branches may even be seen with the naked eye, when they are distended with blood. It can scarcely be doubted that through these capillaries takes place the absorption of fluid from the intestines, which will be immediately stated to convey a portion of their contents directly into the veins (§ 460). The intervals between the reticulations of the blood-vessels appear, from the observations of Wagner, to be filled up with vesicular tissue, forming a delicate membrane. The interior of the villus is always hollow; but the size and form of the cavity appear to vary in different parts. According to Müller, the cylindrical villi, when filled with chyle, have a simple cavity, running from their base to

Fig. 40.

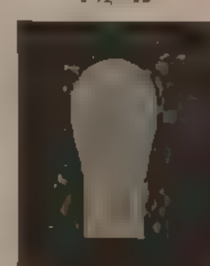
Vessels of an intestinal villus of a *Hare*, from a dry preparation by Döllinger; a, a, veins filled with white injection; b, b, arteries injected red. Magnified about 45 diam.

Fig. 41.

A, apex of intestinal villus from the duodenum of human female. B, a mesh of the vascular net-work, a, a, filled up with delicate vesicular tissue, b. Magnified about 45 diam. (After Wagner.)

their apex; and this cavity communicates with the lacteal vessels, being capable of receiving injection from them. In the broad flat villi, however, there is not a simple cavity, but an irregular net-work of vessels. The accompanying figure represents the appearance offered by the incipient lacteals in the villi of the jejunum of a young man, who had been hung soon after taking a full meal of farinaceous food. The lacteal that issued from each villosity arose by several smaller branches, in some of which free extremities could be traced, whilst others anastomosed with each other. Whether this, or the simple cavity described by Müller, be the ordinary commencement of the lacteals, it is certain that they never open by free orifices on the surface of the intestine, as was formerly imagined; and the same is true of the lymphatics, which originate in the substance of the various tissues.

Fig. 42.



One of the intestinal villi, with the commencement of a lacteal. (After Krause.)

459. In regard to the degree in which the function of Nutritive Absorption is performed by the Lacteals and by the Venous System respectively, considerable difference of opinion has prevailed. When the Absorbent vessels were first discovered, and their functional importance perceived, it was imagined that the introduction of alimentary fluid into the vascular system took place by them alone. A slight knowledge of Comparative Anatomy, however, might have sufficed to correct this error; since no lacteals exist in the Invertebrate animals, the function of Absorption being

performed by the mesenteric veins alone; from which it is evident that the veins possess the power of absorption: and it is scarcely to be supposed that they should not exercise this power in Vertebrate animals also, since their disposition on the walls of the intestinal cavity is evidently favourable to it. On the other hand, the introduction of a new and distinct system of vessels would seem to indicate that they must have some special purpose; and there can be no doubt that the absorption of nutritive matter is that for which they are peculiarly designed. The fluid found in the lacteals is almost invariably the same; being that to which the name *chyle* has been applied, and which may be regarded as imperfectly-elaborated blood. It appears from the uniformity of its composition, which forms a striking contrast with the diversity of the food from which it is obtained, that the lacteals have in some degree the power of *selecting* the particles of which it is composed; and that, whilst they take up such a proportion of each class of alimentary materials, as will rightly blend with the rest in the nutritious fluid, they reject not only the remainder, but also (for the most part at least) any other ingredients which may be contained in the fluid of the intestines. Such may be stated as the general result of the experiments that have been made to determine their function; though it is unquestionable that extraneous substances, especially of a saline nature, occasionally find their way into this system of vessels. This may not improbably be due to a correspondence in the size and form of the ultimate particles of such substances, with those of the materials normally absorbed by the lacteals.*

460. On the other hand, the veins are less concerned in nutritive absorption, but take up from the alimentary canal a portion of almost any fluid matters which it may contain. This seems to have been established by the carefully-conducted experiments of MM. Tiedemann and Gmelin, who mingled with the food of animals various substances, which, by their colour, odour, or chemical properties, might be easily detected in the fluids of the body. After some time the animal was examined; and the result was, that unequivocal traces of the substances were not unfrequently detected in the venous blood and in the urine; whilst it was only in a very few instances that any indication of them could be discovered in the chyle. The colouring matters employed were various vegetable substances; such as gamboge, madder, and rhubarb; the odorous substances were camphor, musk, assafœtida, &c.; while, in other cases, various saline bodies, such as muriate of barytes, acetate of lead and of mercury, and some of the prussiates, which might be easily detected by chemical tests, were mixed with the food. The colouring matters, for the most part, were carried out of the system, without being received either into the veins or lacteals; the odorous substances were generally detected in the venous blood and in the urine, but not in the chyle; whilst of the saline substances many were found in the blood and in the urine, and a very few only in the chyle. A similar conclusion might be drawn from the numerous instances, in which various substances introduced into the intestines have been detected in the blood although the thoracic duct had been tied; but these results are less satisfactory, because even if there is no direct communication (as maintained by

* Experiments upon the function of Absorption in Plants, whose radical vessels have a corresponding power of *selection*, appear likely to assist in elucidating this interesting subject. By the experiments of Dr. Daubeny it has been ascertained, that if a plant absorb any particular saline compound, it can also be made to absorb those which are *isomorphous* with it, though it will reject most others.—See Princ. of Gen. and Comp. Phy. § 294.

many) between the lacteals and the veins in the mesenteric glands, the partitions which separate their respective contents are evidently so thin, that transudation may readily take place through them. The whole question may be regarded as one which remains open to further elucidation.

[In the embryo, as will be hereafter shown, the absorption of the nutritious fluid by cells may be regarded as the preliminary to its introduction into the vessels. The same may be said of the adult; for, as Mr. Goodsir has recently shown,* there is a continual development of cells at the extremity of each villus, during the period when the lacteals are absorbing chyle. These cells appear to be the agents by which the *selection* of the nutritious fluid is accomplished, and by which it undergoes its first preparation for the purposes it is subsequently to fulfil. It is true that the veins also are concerned in absorption; but this is not a *selective* absorption, for they take up any thing that is sufficiently soluble in the fluid they imbibe; and this imbibition has been shown to be almost certainly of a simply physical character. On the other hand, the lacteals clearly possess the power of taking up from the fluid in the digestive cavity those portions which can be rendered subservient to the nutrition of the system, and (for the most part at least) of rejecting every thing else. This has always appeared a wonderful power for absorbent *vessels* to accomplish, but when the operation has been shown to be really effected by *cells*, it is seen to be exactly parallel to that which cells perform in those organisms where nothing else than cellular structure exists.

The following is Mr. Goodsir's account of the process. Whilst the process of digestion is going on there is an increased determination of blood to the mucous membrane of the intestinal canal, and "the minute vesicles which are dispersed among the terminal loops of the lacteals of the villus increased in size by drawing materials from the liquor sanguinis, through the coats of the capillaries, which ramify at this spot in great abundance. Whilst this increase in their capacity is in progress, the growing vesicles are continually exerting their absorbent function, and draw into their cavities that portion of the chyme in the gut which is necessary to supply materials for the chyle. When the vesicles respectively attain in succession their specific size, they burst or dissolve, their contents being cast into the tissue of the villus, as in the case of any other species of interstitial cell. The looped network of lacteals, continually exerting their peculiar function, take up the remains, and the contents of the dissolved chyle cells, as well as the other matters which have already subserved the nutrition of the villus. As long as the cavity of the gut contains chyme, the vesicles of the terminal extremity of the villi continue to develope, to absorb chyle, and to burst; and their remains and contents to be removed by the interstitial absorbent action of the lacteals. When the gut contains no more chyme, the flow of blood to the mucous membrane diminishes, the development of new vesicles ceases, the lacteals empty themselves, and the villi become flaccid. The function of the villi now ceases, till they are again roused into action by another flow of chyme along the gut." Mr. Goodsir subsequently adds, "The same function is performed, the same force is in action, and the same organ, the cell, is provided for absorption of alimentary matters in the embryo and in the adult, in the plant and in the animal. The spongioles of the root, the vesicles of the villus, the last layer of cells on the internal membrane of the included yelk, or the cells which

* See Edinb. New Philos. Journal, July 1842; and British & For. Medical Review, Vol. XIV. p. 567.

cover the vasa lutea of the dependent yelk, and, as I have satisfied myself, the cells which cover the tufts of the placenta, are the parts of the organism in which the alimentary matters first form a part of that organism, and undergo the first steps of the organizing process."

It is evident, then, that there is no essential difference between the lowest cryptogamic plant and the highest animal, in regard to the act of selective absorption; for in both it is accomplished by cells, which imbibe the nutritive substance that is destined for the growth of the structure; but in the former this is applied to their own development alone, whilst in the latter it is speedily given up again by them to the vessels that are to convey it to distant parts, for the renovation of which it is being prepared.—C.]

Absorption by the General Surface.

461. The Mucous Membrane of the alimentary canal is by no means the only channel, through which nutritive or other substances may be introduced into the system. In the lowest tribes of animals, and in the earliest condition of the higher, it would seem as if absorption by the external surface is equally important to the maintenance of life, with that which takes place through the internal reflection of it forming the walls of the digestive cavity. In the adult condition of the higher animals, however, the special function of the latter is so much exalted, that it usually supersedes the necessity of any other supply; and the function of the cutaneous and pulmonary surfaces may be considered as rather that of exhalation than of absorption. But there are peculiar conditions of the system, in which the imbibition of fluid through these surfaces is performed with great activity, supplying what would otherwise be a most important deficiency. It may take place either through the direct application of fluid to the surface, or even through the medium of the atmosphere, in which a greater or less proportion of watery vapour is usually dissolved. This absorption takes place most vigorously, when the system has been drained of its fluid, either by an excess of the excretions, or by a diminution of the regular supply. It may be desirable to adduce some individual cases, which will set this function in a striking point of view. It is well known that shipwrecked sailors, and others, who are suffering from thirst, owing to the want of fresh water, find it greatly alleviated or altogether relieved, by dipping their clothes into the sea, and putting them on whilst still wet, or by frequently immersing their own bodies. Dr. Currie relates the case of a patient labouring under dysphagia in its most advanced stage; the introduction of any nutriment, whether solid or fluid, into the stomach, having become perfectly impracticable. Under these melancholy circumstances, an attempt was made to prolong his existence, by the exhibition of nutritive enemata, and by immersion of the body, night and morning, in a bath of milk and water. During the continuance of this plan, his weight, which had previously been rapidly diminishing, remained stationary, although the quantity of the excretions was increased. How much of the absorption which must have taken place, to replace the amount of excreted fluid, is to be attributed to the baths, and how much to the enemata, it is not easy to say; but it is important to remark that "the thirst, which was troublesome during the first days of the patient's abstinence, was abated, and, as he declared, removed by the tepid bath, in which he had the most grateful sensations." "It cannot be doubted," Dr. Currie observes, "that the discharge by stool and perspiration exceeded the weight of the clysters;" and the loss by the urinary excretion, which increased from 24oz. to 36oz.

under this system, is only to be accounted for by the cutaneous absorption. Dr. S. Smith mentions that a man who had lost nearly 3lbs. by perspiration, during an hour and a quarter's labour in a very hot atmosphere, regained 8oz. by immersion in a warm bath at 95°. for half an hour. The experiments of Dr. Madden* show that a positive increase usually takes place in the weight of the body, during immersion in the warm bath, even though there is at the same time a continual loss of weight by pulmonary exhalation, and by transudation† from the skin. This increase was, in some instances, as much as 5 drachms in half an hour; whilst the loss of weight during the previous half hour had been 6½ drachms; so that, if the same rate of loss were continued in the bath, the real gain by absorption must have been nearly an ounce and a half. Why this gain was much less than in the cases just alluded to, is at once accounted for by the fact, that there was no deficiency, in the latter case, in the fluids naturally present in the body.

462. The quantity of water which may be imbibed from the vapour of the atmosphere, would exceed belief, were not the facts on which the assertion rests, beyond all question. Dr. Dill relates the case of a diabetic patient, who for five weeks passed 24 lbs. of urine every twenty-four hours; his ingesta during the same period amounted to 22 lbs. At the commencement of the disease he weighed 145 lbs.; and when he died, 27 lbs. of loss had been sustained. The daily excess of the excretions over the ingesta could not have been less than 4 lbs.; making 140 lbs. for the thirty-five days during which the complaint lasted. If from this we deduct the amount of diminution which the weight of the body sustained during the time, we shall still have 113 lbs. to be accounted for, which can only have entered the body from the atmosphere. A case of ovarian dropsy has been recorded, in which it was observed that the patient, during eighteen days, drank 692 oz. or 43 pints of fluid, and that she discharged by urine and by paracentesis 1298 oz. or 91 pints, which leaves a balance of 606 oz. or 38 pints, to be similarly accounted for.‡ The following remarkable fact is mentioned by Dr. Watson in his Chemical Essays. "A lad at Newmarket, having been almost starved, in order that he might be reduced to a proper weight for riding a match, was weighed at 9 A. M., and again at 10 A. M.; and he was found to have gained nearly 30 oz. in weight in the course of this hour, though he had only drank half a glass of wine in the interim." A parallel instance was related to the Author by the late Sir G. Hill, then Governor of St. Vincent. A jockey had been for some time in training for a race in which that gentleman was much interested, and had been reduced to the proper weight. On the morning of the trial, being much oppressed with thirst, he took one cup of tea; and shortly afterwards his weight was found to have increased 6 lbs.; so that he was incapacitated for riding. Nearly the whole of the increase in the former case, and at least three-fourths of it in the latter, must be attributed to cutaneous absorption; which function was probably stimulated by the wine that was taken in the one case, and by the tea in the other.

463. Not only water, but substances dissolved in it, may be thus intro-

* Prize Essay on Cutaneous Absorption, pp. 59—63.

† That part of the function of cutaneous transpiration which consists in simple exhalation, is of course completely checked by such immersion; but that which is the result of an actual secreting process in the cutaneous glands (Chap. XII.) is increased by heat, even though this be accompanied with moisture.

‡ Madden, loc. cit.

duced. It has been found that, after bathing in infusions of madder, rhubarb, and turmeric, the urine was tinged with these substances; and that a garlic plaster affected the breath, when every care was taken, by breathing through a tube connected with the exterior of the apartment, that the odour should not be received into the lungs.* Gallic acid has been found in the urine, after the external application of a decoction of a bark containing it; and the soothing influence, in cases of neuralgic pain, of the external application of cherry-laurel water, is well known. Many saline substances are absorbed by the skin, when applied to it in solution; and it is interesting to remark that, contrary to what happens in regard to the absorption of these from the alimentary canal, they are for the most part more readily discoverable in the absorbents than in the veins. This is probably due to the fact, that the imbibition of them is governed entirely by physical laws; in obedience to which, they pass most readily into the vessels which present the thinnest walls and the largest surface. In the intestines, the vascular plexus on each villus is far more extensive than the ramifying lacteal which originates in it; and as the walls of the veins are thin, there is considerable facility for the entrance of saline and other substances into the general current of the circulation: but in the skin, the lymphatics are distributed much more minutely and extensively than the veins; and soluble matters, therefore, enter them in preference to the veins. In none of the experiments referred to, was any friction employed to hasten absorption; this altogether changes the condition of the function.

464. It is not, however, from the external world alone, that Animals derive the materials of their nutrition. It has been stated (§ 84) that the necessity for a constant supply of food, arises from the continual decomposition which is taking place within the living body; and it will be hereafter shown, that this decomposition is connected with the death of the cells, of which the several parts are constructed, these having an independent life of their own, and consequently a limited duration, which has no immediate connection with that of the organism at large. In every portion of the body, therefore, materials for nutrition are continually being set free; and we find a peculiar provision for the re-introduction of these into the circulating fluid. All animals which have a *lacteal* system have also a *lymphatic* system, closely corresponding to it in aspect, but consisting of vessels that are distributed through the whole body, instead of on the intestinal surface only, permeating almost every tissue, and in many forming a most minute plexus. These vessels pass, like the lacteals, through conglobate glands, in which they are brought into intimate relation with blood-vessels; and they empty their contents into the same receptacle, so as to pour them into the blood in precisely the same manner. The evident conformity in the nature of the fluid which these two sets transmit, joined to the fact of the fluid lymph, like the chyle, being conveyed into the general current of the circulation just before the blood is again transmitted to the system at large, almost inevitably leads to the inference that the lymph is, like the chyle, a nutritious fluid, and is not of an excrementitious character, as formerly supposed. The following is the most recent comparative analysis of the two, as performed by Dr. G. O. Rees; the fluids were procured from the lacteal and lymphatic vessels of a donkey, previously to their entrance into the thoracic duct; the animal was killed seven hours after a full meal.

* Dunglison's Physiology, Vol. II. p. 85, 4th Ed.

	Chyle.	*Lymph.*
Water - - - - - - -	90·237	96·536
Albuminous matter - - - -	3·516	1·200
Fibrinous matter - - - -	0·370	0·120
Animal extractive matter soluble in water and alcohol	0·332	0·240
Animal extractive matter soluble in water only -	1·233	1·319
Fatty matter - - - - - -	3·601	a trace
Salts;—Alkaline chloride, sulphate and carbonate, with traces of alkaline phosphate, oxide of iron	0·711	0·585
	100·00	100·00

From this analysis it appears that the chief chemical difference between the chyle and lymph consists in the much larger *proportion* of assimilable substances,—albumen, fibrin, and fatty matter,—contained in the former: the nature and amount of the less clearly-defined animal principles, and of the saline ingredients, appear to be nearly identical in both.

465. Hence it can scarcely be doubted that, to use Dr. Prout's expression, "a sort of digestion is carried on in all parts of the body." That a part of the products of interstitial decomposition may be subsequently assimilated, appears indisputable; for in no other way can we account for the fact, that animals may live for a time on their own solids. This is particularly evident in the case of the hybernating animals, which retire to their winter quarters loaded with fat, and come forth quite lean in the spring; and in such a case we must believe, not only that the lymphatics select from the products of spontaneous decomposition those which are fit to be again assimilated, but that an actual change is effected in the fatty matter, by means of some action of the fluids upon it, which prepares it to be thus absorbed. It would not seem improbable that, when the gastric secretion is suspended, for want of the necessary excitement, its materials may accumulate in the blood (as it will hereafter appear that those of the other secretions will do) and may thus act upon the tissues of the body itself. A very similar phenomenon is observed in Vegetables. In the neighbourhood of most parts which are at a certain time to undergo rapid development, we find laid up a deposit of starchy matter,—the peculiar character of which is, that it is not dissolved by the ordinary circulation of fluid through the cells containing it, but that it is capable of being thus dissolved by a very simple chemical process; and this process takes place exactly when it is necessary that this store should be appropriated. Thus, of the seed, the principal bulk is composed of starch, which is converted into sugar during the process of germination; and the same may be said of the tuber of the potato, which chiefly consists of starch that is converted into sugar during the development of its eyes or buds. The agent in the process is a substance called diastase, which is stored up in the neighbourhood of the embryo or of the bud, and is carried by its vessels into the midst of the amylaceous deposit, when its development commences. This diastase may be obtained in a separate form; and produces its characteristic effect as well in the laboratory of the chemist, as in the vegetable organism.*

466. It may be stated, then, as a general fact, that the function of the Absorbent System is to take up, and to convey into the circulating apparatus, such substances as are capable of appropriation to the nutritive process; whether these substances be directly furnished by the external world, or be

* See Principles of General and Comparative Physiology, § 403.

derived from the disintegration of the organism itself. We have seen that, in the lacteals, the selecting power is such, that these vessels are not disposed to convey into the system any substances but such as are destined for this purpose; and that extraneous matters are absorbed in preference by the mesenteric veins. The case is different, however, with regard to the lymphatics; for there is reason to believe that they are more disposed than the veins to the absorption of other soluble matters; especially when these are brought into relation with the skin, through which the lymphatics are very profusely distributed. Thus, when irritating substances are rubbed on the skin, red streaks soon appear in the course of the lymphatics, and the absorbent glands soon become swollen and inflamed. It is well known that this is also the case in regard to certain poisonous substances which may have been absorbed through slight wounds; such as the matter of the dead body introduced in dissection, that of the pustule maligne of cattle (which is said to have produced fatal consequences, even when no breach of surface has existed in the skin with which it has been in contact), the syphilitic virus, and other similar morbific agents. The absorbent power of the lymphatics of the skin is well shown by the following experiment. A bandage having been tied by Schreger round the hind-leg of a puppy, the limb was kept for twenty-four hours in tepid milk; at the expiration of this period, the lymphatics were found full of milk; whilst the veins contained none. In repeating this experiment upon a young man, no milk could be detected in the blood drawn from a vein. It has been shown by Müller that, when the posterior extremities of a frog were kept for two hours in a solution of prussiate of potass, the salt had freely penetrated the lymphatics, but had not entered the veins. It does not follow, however, from these and similar experiments, that in all tissues the lymphatics absorb more readily than the veins; for we may conceive a good deal to depend upon the relative facility with which, from the arrangement of these two kinds of vessels respectively, the fluid can gain access to them. Thus in the skin, the lymphatic plexus is more minute, and nearer the surface than the venous plexus; in the lungs, on the other hand, the capillary blood-vessels are much more freely exposed to the surface of the air-cells, than are the lymphatics; and we should therefore expect the former to absorb more readily. This appears from experiment to be the fact; for, when a solution of prussiate of potass was injected by Mayer into the lungs, the salt could be detected in the serum of the blood much sooner than in the lymph, and in the blood of the left cavities of the heart, before it had reached that of the right.

467. Since the time of Hunter, who first brought prominently forwards the doctrine alluded to, it has been commonly supposed that the function of the lymphatics is to remove, by interstitial absorption, the effete matter, which is destined to be carried out of the system; and any undue activity in this process (such as exists in ulceration), or any deficiency in its energy (such as gives rise to dropsical effusions, and other collections of the same kind), have been attributed to excess or diminution in the normal operation of the absorbent system. From what has been stated, however, it appears that the special function of the lymphatics, like that of the lacteals, is *nutritive* absorption; and that the reception of any other substances into their interior, must be looked upon as resulting simply from the permeability of their walls. This statement applies to the not unfrequent occurrence of the absorption of bile, and other fluids, from the walls of the cavities in which they were collected; with regard to the absorption of pus, however, which has been occasionally noticed to take place, both from internal collections, and from open ulcers, it may be remarked that the lymphatic vessels were

not improbably laid open by ulceration, since in no other way can be understood the entrance of globules so large as those of pus into their interior. If this view of the function of the lymphatics be correct, it follows that we must attribute to the blood-vessels the absorption of the truly effete particles; and in this there would seem no improbability. We know that venous blood contains the elements of two important excretions, that of the lungs and that of the bile, in a far higher amount than does arterial blood; and we shall hereafter see, that there is a certain portion of the fluid, which consists of "ill-defined animal principles" that seem ready to be thus thrown off. Moreover, the materials of a large part of the excretory products are probably derived from the processes of assimilation themselves; each tissue appropriating the principles which it needs, and leaving the remainder in the fluid as superfluous matter. It may be further remarked, that the reciprocal part which Hunter imagined the arteries and lymphatics to perform in the function of nutrition, is quite inconsistent with what is now known of the nature of that process; for, as will subsequently appear, it entirely consists in a reaction between the tissues and the nutritious fluid, in which the vessels have no share save as the channels of supply. When these channels are obstructed, or the supply of new matter is cut off in any other way, the removal of the old by interstitial absorption becomes evident; and that this is accomplished at least as much by the veins as by the lymphatics appears from the fact, that in some tissues, in which it may take place with rapidity (such as bone) lymphatics do not exist.

Supply of Food required by Man.

468. The *quantity* of food, required for the maintenance of the Human body in health, varies so much with the age, sex, and constitution of the individual, and the circumstances in which he may be placed, that it would be absurd to attempt to fix any standard which should apply to every particular case. The appetite is the only sure guide for the supply of the wants of each; but its indications must not be misinterpreted. To eat when we are hungry is an evidently natural disposition; but to eat as long as we are hungry may not always be prudent. Since the feeling of hunger does not depend so much upon the state of fulness or emptiness of the stomach, as upon the condition of the general system, it appears evident that the ingestion of food cannot *at once* produce the effect of dissipating it, though it will do so after a short time; so that, if we eat with undue rapidity, we may continue swallowing food long after we have taken as much as will really be required for the wants of the system; and every superfluous particle is not merely useless but injurious. Hence, besides its other important ends, the process of thorough mastication is important, as prolonging the meal, and giving time to the system to become acquainted (as it were) that the supply of its wants is in progress; so that its demand may be abated in due time to prevent the ingestion of more than is required. It is very justly remarked by Dr. Beaumont, that the cessation of this demand, rather than the positive sense of satiety, is the proper guide. "There appears to be a sense of perfect intelligence conveyed to the encephalic centre, which, in health, invariably dictates what quantity of aliment (responding to the sense of hunger and its due satisfaction) is naturally required for the purposes of life; and which, if noticed and properly attended to, would prove the most salutary monitor of health, and effectual preventive of disease. It is not the sense of satiety, for this is beyond the point of healthful indulgence, and is Nature's earliest indication of an abuse and overburden of her powers to

replenish the system. It occurs immediately previous to this; and may be known by the pleasurable sensations of perfect satisfaction, ease, and quiescence of body and mind. It is when the stomach says, *enough;* and it is distinguished from satiety by the difference of sensations,—the latter saying *too much.*" Every medical man is well aware how generally this rule is transgressed; some persons making a regular practice of eating to repletion; and others paying far too little attention to the preliminary operations, and thus ingesting more than is good for them, even though they may actually leave off with an appetite.

469. Although no universal law can be laid down for individuals, however, it is a matter of much practical importance to be able to form a correct *average* estimate; and there is no more difficulty in accomplishing this, than there is in forming tables of mortality. It is by estimating the average duration of life, that Insurance Companies make their calculations of the probable duration of any *one;* and though the actual result may, in every individual case, be different from that estimate, yet it holds good perfectly well for a large number. It is from the experience afforded by the usual consumption of food by large bodies of men, therefore, that our data are obtained; and these data are sufficient to enable us to predict with tolerable accuracy what will be required by similar aggregations, though they can afford no guide to the consumption of individuals. We shall first consider the quantity sufficient for men in regular active exercise; and then inquire how far that may be safely reduced for those who lead a more sedentary life. The Diet-scale of the British Navy may be advantageously taken as a specimen of what is required for the first class. It is well known that an extraordinary improvement has taken place in the health of seamen during the last 80 years; so that three ships can now be kept afloat with only the same number of men which were formerly required for two. This is due to the improvement in the quality of the food, in combination with other prophylactic means. At present it may safely be affirmed that it would not be easy to conceive of any diet-scale more adapted to answer the required purpose. The health of crews that have been long afloat, and have been exposed to every variety of external conditions, appears to be preserved (at least when they are under the direction of judicious officers), to the full as well as that of persons subject to similar vicissitudes on shore; and there can be no complaint of insufficiency of food, although the allowance cannot be regarded as superfluous. It consists of from 31 to 35½ ounces of *dry* nutritious matter daily; of this 26 oz. are vegetable, and the rest animal; 9 oz. of salt meat, or 4½ oz. fresh, being the allowance of the latter. This is found to be amply sufficient for the support of strength; and considerable variety is produced by exchanging various parts of the diet for other articles. This, however, is sometimes done erroneously; thus 8 oz. of fresh vegetables, which contain only 1½ oz. of solid nutriment, are exchanged for 12 oz. of flour, which is almost all nutritious. Sugar and Cocoa are also allowed; partly in exchange for a portion of the spirits formerly served out, the diminution of which, especially in the case of boys, has been attended with great benefit.

470. Another government scale is that by which troops are victualled on the voyage to the East Indies. The diet is essentially the same with that of seamen; but as there is not the same necessity for exertion, it is diminished to 23½ oz. of dry vegetable matter, and 8 oz. of animal food per day, being in the whole about one-tenth less than that of seamen. But this allowance is probably too liberal, considering the difference of circumstances, and the inactive life the soldiers lead. The health of the troops is almost always good on landing; and scurvy rarely appears among them,

although it sometimes shows itself among the crews of private ships, in consequence of the want of proper precautions. This scale is intermediate between what is required for men in active and laborious exercise, and that which is adequate for persons in confinement, such as prisoners and the inmates of poor-houses. In the case of prisoners, the diet should of course be as spare as possible consistently with health; but it should be carefully modified, in individual cases, according to several collateral circumstances, such as depression of mind, compulsory labour, previous intemperate habits, and especially the length of confinement. It has been supposed by some that prisoners require a fuller diet than persons at large; this is probably erroneous; but more variety is certainly desirable, to counteract, as far as possible, the depressing influence of their condition upon the digestive powers. The circumstances which occurred at the Millbank Penitentiary in 1823, form a lamentable warning against the reduction of the diet-scale to an insufficient amount. The allowance to the prisoners had formerly been from 31 to 33 oz. of dry nutriment daily, and the prison was considered healthy; but in 1822, it was reduced to 21 oz. The health of the prisoners continued unbroken for nearly six months; but scurvy then showed itself unequivocally; and out of 860 prisoners, 437, or 52 per cent., were affected with it. The effect of previous confinement here became remarkable; for those were chiefly attacked who had been in the prison for two years, a year, or six months. Again, the prisoners employed in the kitchen, who had 8 oz. of bread additional per day, were not attacked, except three who had only been there a few days. After the epidemic had spread to a great extent, it was found that the addition of 8 oz. to the daily allowance of vegetable food, and ½ oz. to the animal, facilitated the operation of the remedies which were used for the restoration of the health of the prisoners. The effects of confinement have been further shown in the experience of the Edinburgh House of Refuge, which was first established in 1832 for the reception of beggars during the cholera, and which has been continued to the present time. The diet was at first a quart of oatmeal porridge for each person, morning and evening; and at dinner 1 oz. of meat, in broth, with 7 oz. of bread; making altogether about 23 oz. of solid food a day. During some months, this diet seemed to answer very well; the people went out fatter than they came in, owing to the diet being better than that to which they had been accustomed; but afterwards, a proneness to disease manifested itself in those who had been residents there for a considerable time, and the diet was therefore somewhat increased, with good effect. The quantity of animal food was probably here too small; and the total weight might still have been sufficient, if it had been differently apportioned. In a convict-ship which took out 433 prisoners to New Holland in 1802, the mortality was very trifling, and the general health good, although these prisoners were supported on 16 oz. of vegetable food, and 7½ oz. of animal food per day,—a quantity which was found to be perfectly sufficient for them. The aged inmates of work-houses, especially those who have been accustomed to poor food during their whole lives, require much less than this; their vital functions being comparatively inactive, and their amount of labour or exercise small. In the Edinburgh work-house, of which the inmates have usually good health, they are fed upon oatmeal porridge morning and evening, with barley-broth at dinner; the total allowance of dry animal nutriment is about 17 oz.,—namely 13 oz. vegetable, and 4 oz. animal.

471. The diet of children in Public Institutions is a subject of much interest, from the large number who are supported in this country by cha-

rity, during the ages of from 7 to 14 years. Every one who has had much experience among the poor, must be aware how frequently the growth is stunted for want of an adequate supply of food; but it is certainly not less common among the higher classes, and even amongst those just raised above absolute poverty, to meet with children suffering under various disorders, which may be distinctly traced to an overloaded state of the system. In the Edinburgh Children's poor-house, the age of the inmates is from 7 to 14 years; their diet consists of milk and porridge, barley-broth and bread, amounting to 13 oz. of vegetable food, and 3 oz. of animal. In Heriot's Hospital, of which the funds are ample, meat and potatoes are allowed for dinner, making the total about 16½ oz. of vegetable, and 4½ oz. of animal food. Of these scales, the first is probably rather too low, and the second too high. Both establishments are healthy; but in the Poor-house there is the least mortality.

472. The diet of patients in the Hospitals falls still more strictly under the cognizance of the Medical Officers; and it seems desirable to introduce here a few remarks as to what is required, for the guidance of those who may be engaged in framing such a scale. There can be little doubt that, as a whole, the diet of patients in English Hospitals is much too high, being far better than that to which the same class of persons is accustomed in health; this is attended with injury to the patients, and with increased expense to the institution; and it has further the injurious effect of tempting the patients to stay in the hospital for a longer time than is necessary. There are, however, considerable diversities in the mode of living, in different parts of the country, which render it undesirable to lay down any fixed standard for all; and every plan will need great modification, according to the particular constitution and condition of individuals. As a general rule it may be stated, that patients who are labouring under slight diseases, the greater number of those under surgical treatment, and convalescents from acute diseases, should have a diet much like that of their ordinary food, but rather less in quantity. The following scale of the diet adopted in the Edinburgh Infirmary is here introduced, as showing that a much smaller amount of animal food than is commonly afforded in England, is usually quite sufficient. The *ordinary* diet, upon which by far the greater number of the patients are fed, consists of a pint of porridge with 5¼ oz. of bread and 7 oz. of milk, morning and evening; for dinner there are broth and vegetables, the former containing about 4½ oz. of animal matter, the latter weighing 14 oz. *Full* diet consists in the addition of 8 oz. of meat three days a week. As a ground of comparison, it may be mentioned that the estimate already given, for the amount of *dry* nutritive matter required by a young adult in full health and activity, would allow but 10 oz. of bread for breakfast, 12 oz. of meat, with half the quantity of vegetables for dinner, and 8 oz. of vegetable food at other meals; many persons, however, are in the habit of taking double that quantity, to their own great detriment.*

473. The smallest quantity of food upon which life is known to have been supported with vigour, during a prolonged period, is that on which Cornaro states himself to have subsisted. This was no more than 12 oz. a day, chiefly of vegetable matter, for a period of 58 years. There is only one instance on record in which his plan was followed; and there are pro-

* For a large part of the information he has given on this subject, the author is indebted to Professor Christison's valuable Lectures on Dietetics, which form part of his Course on *Materia Medica*.

bably few who could long persevere in it, at least among those whose avocations require much mental or bodily exertion. It is certain, however, that life with a moderate amount of vigour may be preserved for some time, with a very limited amount of food, especially when the individuals are much exposed to the air; this appears from the records of shipwreck and similar disasters. In regard, however, to those who have been stated to fast for a period of months or even years, taking no nutriment, but maintaining an active condition, it may be safely asserted that they were impostors,—probably possessing unusual powers of abstinence, which they took care to magnify. It is yet a matter of doubt, however, whether, in particular conditions of the system, in which the circulation, respiration, &c., are reduced to the low condition of functional activity which they exhibit in hybernating animals, there may not be, as in these, a considerable power of abstaining from food. The time during which life can be supported under total abstinence, is usually stated to vary from 8 to 10 days; the period may be greatly prolonged, however, by the occasional use of water, and still more by a very small supply of animal food. In a case recorded by Dr. Willan, of a young gentleman who starved himself, under the influence of a religious delusion, life was prolonged for 60 days; during the whole of which time nothing else was taken than a little orange juice. In a somewhat similar case which occurred under the Author's notice, in the person of a young French lady, more than 15 days elapsed between the time that she ceased to eat regularly, and the time of her being compelled to take nourishment; during this period she took a good deal of exercise, and her strength seemed to suffer but little, although she swallowed solid food only once, and then in small quantity. If the cessation of muscular exertion be complete, it seems that life is usually more prolonged, than where exercise of any kind is performed; and this is what might naturally be expected.

474. Of the quantity which *can* be devoured at a time, it is scarcely the place to speak; since such feats of gluttony only demonstrate the extraordinary capacity which the stomach may be made to attain by continual practice. Many amusing instances are related by Captain Parry in his Arctic Voyages; in one case, a young Esquimaux, to whom he had given (for the sake of curiosity) his full tether, devoured in four-and-twenty hours, no less than 35 lbs. of various kinds of aliment, including tallow candles. A case has recently been published of a Hindoo, who can eat a whole sheep at a time; this probably surpasses any other instance on record. The half-breed *voyageurs* of Canada, according to Captain Franklin, and the wandering Cossacks of Siberia, as testified by Captain Cochrane, habitually devour a quantity of animal food, which would be soon fatal to any one unused to it. The former are spoken of as very discontented when put on a short allowance of 8lbs. of meat a day, their usual consumption being from 12 to 20lbs. That a much larger quantity of food than that already specified may be taken with perfect freedom from injurious consequences, under a particular system of exercise, &c., appears from the experience of those who are *trained* for feats of strength, pugilistic encounters, &c. The ordinary belief, that the athletic constitution cannot be long maintained, appears to have no real foundation; nor does it appear that any ultimate injury results from the system being persevered in for some time. That trained men often fall into bad health on the cessation of the plan, is probably owing in part to the intemperance and other bad habits of persons of the class usually subjected to this discipline. The effects of trainers' regimen are hardness and firmness of the muscles, clearness of the skin, capability of

bearing continued severe exercise, and a feeling of freedom and lightness (or 'corkiness') in the limbs. During the continuance of the system, it is found that the body recovers with wonderful facility from the effects of injuries; wounds heal very rapidly; and cutaneous eruptions usually disappear. Clearness and vigour of mind, also, are stated to be results of this plan; and it is probable that, where persevering attention and intense application are necessary, a modification of this system, in which due allowance should be made for the diminished quantity of exercise, would be found advantageous.*

CHAPTER IX.

OF THE CIRCULATION.

475. The circulation of nutritive fluid through the body has for its object, to convey to every part of the organism the materials for its growth and renovation; and also to afford to every part the means of absorbing oxygen from the atmosphere, and of giving up to this the carbonic acid which it is continually generating. The extent, therefore, to which an apparatus for this purpose is developed in the Animal kingdom, is partly dependent upon the degree in which the function of nutritive absorption is limited to one part of the body, and partly upon the degree of limitation of the respiratory apparatus. Where the digestive cavity itself extends through the whole system, so that every part can absorb at once from its parietes, and where the whole external surface is adapted by its softness and permeability to expose the fluids of the body to the aerating medium around, there is no necessity for any transmission of fluid from one part to another; and accordingly, in the lowest animals, which are thus formed, no true circulation exists. Again, in the Insect tribes, in whose bodies the absorption of fluid can only take place at fixed points, there is a circulation for the purpose of transmitting the absorbed matter to the remote parts of the body; but, as every part of the interior is permeated by air, the second of the above-named purposes is already answered; and the curcuit of the blood through the vessels, therefore, is not accomplished with the energy and activity, which, from the vigorous movements performed by these little beings, might have been supposed necessary. On the other hand, in the Mollusca, the absorption of fluid is limited, and the respiratory action

* The food of the athletæ in Greece consisted chiefly of pork, which was broiled or roasted, and eaten with unleavened bread. The use of fluids, especially of fermented liquors, was very sparing. The method of training employed by Jackson (a celebrated trainer of prize-fighters in modern times), as deduced from his answers to questions put to him by John Bell, was to begin on a clear foundation, by an emetic and two or three purges. Beef and mutton, the lean of fat meat being preferred, constituted the principal food; veal, lamb, and pork were said to be less digestible ("the last purges some men"). Fish was said to be "a watery kind of diet;" and is employed by jockeys who wish to reduce weight by sweating. Stale bread was the only vegetable food allowed. The quantity of fluid permitted was 3½ pints; but fermented liquors were strictly forbidden. Two full meals, with a light supper, were usually taken. The quantity of exercise employed was very considerable, and such as few men of ordinary strength could endure. This account corresponds very much with that which Hunter gave of the North American Indians, when about to set out on a long march.

equally so; and among these we find that the circulation is performed with nearly as much vigour as it is in the Vertebrata.

476. In Man, as in other Vertebrated animals, there is a regular and continuous movement through the vascular system; and upon the maintenance of this, the activity of all parts of the organism is dependent. The course of the blood may be likened to the figure 8; for there are two distinct circles of vessels, through which it is transmitted, and the heart is placed at the junction of these. The systemic and pulmonary circulations are entirely separate, and might be said to have distinct hearts, for the left and right sides of the heart, which are respectively appropriated to these, have no direct communication (in the perfect adult condition, at least), and are merely brought together for economy of material. At an early period of fœtal life, as in the permanent state of the Dugong, the heart is so deeply cleft, from the apex towards the base, as almost to give the idea of two separate organs. Each system has its own set of arteries, or efferent vessels, and veins or afferent trunks; these communicate at their central extremity by the heart; and at their peripheral extremity by the capillary vessels, which are nothing else than the minutest ramifications of the two systems, inosculating into a plexus. The systemic arteries all proceed from one trunk, the aorta, which first ascends and gives off branches to the head and superior extremities, then descends through the thorax and abdomen, giving off branches to the parts near which it passes, and terminates in the two large trunks that proceed to the inferior extremities. Now it has been commonly asserted, that the calibre of the arterial system is continually on the increase as it becomes more distant from the heart, since at each subdivision, the diameter of the branches is considerably greater than that of the trunk; so that the combined cavity of the whole might be said to form a cone, of which the base is in the peripheral ramifications, and the apex at the heart. Such an idea is quite inconsistent, however, with the fact that the pressure of the blood upon the walls of the arteries, as ascertained by the hæmadynameter, is, under ordinary circumstances, the same in every part of the system; and it has been recently shown* to be inconsistent with the results of actual measurement, when these are rightly interpreted. For, according to a well-known geometrical law, the *areas* of circles are as the *squares* of their *diameters;* and, as the calibre of a tube is estimated by its area, not by its diameter, it follows that, in comparing the size of a trunk with that of its branches, we are to square the diameter of the former, and compare the result with the sum of the squares of the diameters of the branches. When this is done, there is found to be a very close correspondence. The following table gives the result of eight measurements, taken with a view to determine the question. The first three were taken from the mesenteric artery of a sheep; the next three from the aorta and iliac arteries; the last two from the horse.

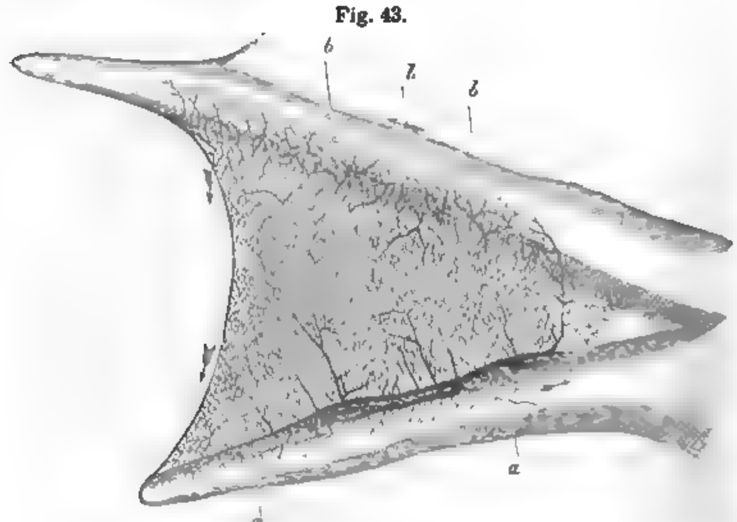
	TRUNK.		BRANCHES.	
	Diameter.	*Square.*	*Diameters.*	*Sum of Squares.*
I.	9	81	7·5+5	81·25
II.	7·2	51·64	6+4	52
III.	3·5	12·25	3+2	13
IV.	7·0	49	5+5	50
V.	17	289	10+10+9·5	290·25
VI.	10	100	7+7+2	102
VII.	4·5	20·25	3·5+3	21·25
VIII.	8	64	4+7	65

* Ferneley in Medical Gazette, Dec. 7, 1839.

The discrepancy between the two results must be considered extremely small, when it is stated that the *unit*, in the above measurements, is no more than one-fortieth of an inch; and when it is remembered that any error in the measurement is greatly increased in the calculation.

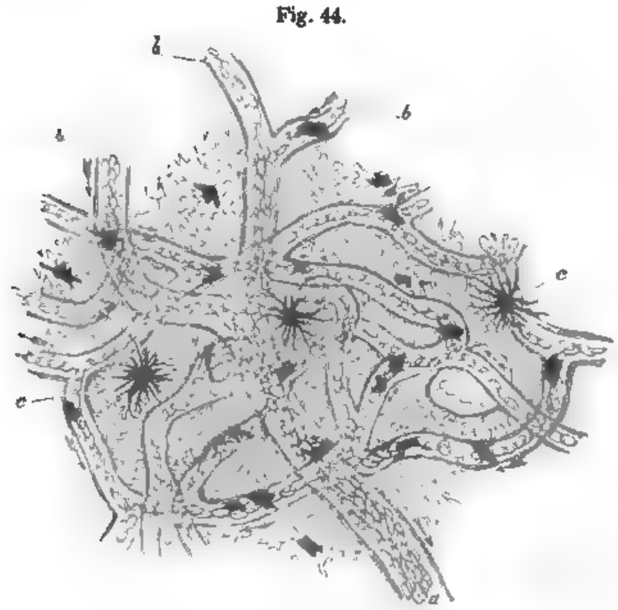
477. The ultimate ramifications of the arteries usually pass so insensibly into those of the veins, that the line of demarcation between them cannot be

Fig. 43.



Web of *Frog's* foot, stretching between two toes, magnified 3 Diam.; showing the blood-vessels, and their anastomoses; *a*, *a*, veins; *b*, *b*, *b*, arteries.

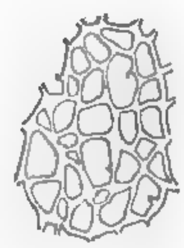
Fig. 44.



Capillary circulation in a portion of the web of a *Frog's* foot, magnified 110 Diam.; *a*, trunk of vein; *b*, *b*, its branches; *c*, *c*, pigment-cells. (After Wagner.)

distinctly drawn. Hence there is no ground for the assumption that the *capillaries* form a distinct system of vessels in which the arteries terminate and the veins arise. They are in no respect different, except in size, from the other vessels. Their anastomosis is very frequent, so that a minute network is formed by them; but this is also seen in the distribution of the larger vessels. It has been maintained by some, that they are mere passages, channelled out of the tissues through which they convey the blood; but this, again, is incorrect, for recent microscopical observations have shown that they have distinct parietes, and that these are composed of a fibrous structure analogous to the muscular. Their mode of origin, again, refutes such a supposition; for there can be no doubt that they are produced, in any newly-forming tissue, not by the retirement of its cells, one from the other, so as to leave passages between them,—but by the formation of communications among certain cells, whose cavities become connected with each other, so as to constitute a plexus of tubes, of which the original cell-walls become the parietes. The process may be most clearly traced in Plants, in which (among the Phanerogamia at least) a distinct system of capillary vessels exists; but it may also be seen in the germinal membrane of the ovum, in which the capillaries distinctly originate before the trunks; and this view of it is confirmed by the fact, that the nuclei or cytoblasts of the original cells, may often be seen imbedded in the walls of the fully-formed capillary vessels. In regard to the size of the capillary vessels, there is considerable variation; some being so small as only to admit globules of blood in single file; but others, passing directly between arteries and veins, admitting several rows at once. From the measurements of Weber, Müller, and others, it appears that the capillaries in Man vary from about $\frac{1}{3500}$th to $\frac{1}{1500}$th of an inch; whilst the blood-corpuscles vary from about $\frac{1}{3000}$th to $\frac{1}{3500}$ of an inch in diameter. As the capillaries cannot be examined in the human body until after death, and then only by means of forcible injections, these measurements may be somewhat inaccurate. To the larger tubes, which may perhaps be more numerous in cold-blooded than in warm-blooded vertebrata), some would deny the term capillary; but in the sense in which that word is here employed, it is strictly applicable to all those minute vessels which connect the arterial and venous systems.

Fig. 45.



First appearance of blood-vessels in the vascular layer of the germinal membrane of a *Fowl* at the 36th hour of incubation. (After Wagner.)

478. The size of the capillary vessels in any part is continually undergoing variation; sometimes all of them enlarging or contracting simultaneously; and one sometimes contracting whilst others enlarge. In regard to the first of these phenomena, more will be said hereafter; the second is here noticed, because it explains an occasional appearance, on which some have founded their belief in the non-existence of distinct parietes to these vessels. In watching the capillary circulation in any transparent part, we not unfrequently see the globules of blood running into passages of the tissue which we did not perceive before; but on a more careful examination, the observer may satisfy himself, that these passages existed previously, and that the fluid part of the blood was transmitted through them; the stoppage of the red particles being in a great measure dependent on some partial or local impediments. The compression of one of the small arteries, for instance, will generally occasion an oscillation of the globules of blood in the smallest capillaries, which will be followed by the disappearance of

some of them; but when the obstruction is removed, the blood soon regains its former velocity and force, and flows exactly in the same passages as before.* It may also be frequently observed, that the rate of motion is very different in the different parts of the network; and that an entire stagnation of the current sometimes takes place in some particular tube, the motion of the globules recommencing, but in an opposite direction. Irregularities of this kind, however, are more frequent when the heart's action is partially interrupted; as it usually is by the pressure to which the tadpole or other animal must be subjected, in order to allow microscopic observations to be made upon its circulation. Under such circumstances the varieties in the capillary circulation, induced by causes purely local, become very conspicuous; for when the whole current has nearly stagnated, and a fresh impulse from the heart renews it, the movement is not by any means uniform (as it might have been expected to be) through the whole plexus supplied by one arterial trunk, but is much greater in some of the tubes than it is in others; the variation being in no degree connected with their size, and being very different at short intervals.

479. The opinion was long entertained, that there are vessels adapted to the supply of the white or colourless tissues, which carry from the arteries the liquor sanguinis or fluid portion of the blood, leaving the globules behind. Many objections might be raised against such a supposition; one of the most obvious of which, is the mechanical obstacle that would be created at the entrances to such a system of tubes, by the retention of the globules in the larger vessels from which they diverged. No such vessels have ever been observed; and it may be safely affirmed that the supposition of their existence is not required. For any one who observes the smaller capillary vessels may perceive, that the current of blood which passes through them is entirely free from colour, as the corpuscles themselves appear to be, when spread out in a single layer. Tissues which are rather scantily permeated by such vessels, therefore, may still be white; and it is only where the network is very close, and the quantity of blood which passes through it is consequently great, that a perceptible colour will be communicated by the red corpuscles. On the other hand, the supposition that nutrition can only be carried on by means of capillary vessels is entirely gratuitous, as will be hereafter shown (Chap. XI.); and it would appear from the late researches of Mr. Toynbee,† that cartilages in general, the cornea,‡ crystalline lens, and vitreous humour, together with the epidermoid appendages, are entirely destitute of them. He has demonstrated, by means of injections, that the arteries, which previous anatomists had supposed to penetrate into their substance, either as serous vessels, or as red vessels too minute for injection, actually terminate in veins before reaching them; he also shows that around these non-vascular tissues there are numerous vascular convolutions, large dilatations and intricate plexuses of blood-vessels, the object of which he believes to be, to arrest the progress of the blood, so that its nutrient portion may penetrate into and be diffused through them. There is, as will hereafter appear, no essential difference between the nutrition of the non-vascular tissues, and that of the islets in the midst of the network of capillary vessels which traverses the most vascular (Fig. 44). In both cases,

* Dr. Allen Thomson, in Cyclop. of Anat. and Phys., Art. Circulation.
† Proceedings of the Royal Society. No. 48.
‡ This statement refers to the *true* cornea. The outer layer of what is commonly termed the cornea, which is really a continuation of the conjunctival membrane, contains vessels, which frequently become enlarged in inflammation, but which do not dip down into the substance beneath.

the nutrient materials conveyed by the blood are absorbed by the cells of the tissue immediately adjoining the vessels, and are imparted by them to others which are further removed; and the only variation that exists, is in the amount of the portion of tissue which has to be thus traversed. There is great variety in this respect, among the tissues that *are* traversed by vessels; and we are only required to extend our ideas, from the largest of the islets which we find in these, to the still more isolated structures of which the non-vascular tissues are composed. In the Vegetable Kingdom, as among the lowest Animals, there are entire organisms of considerable size, throughout which nutriment is conveyed by mere transudation from cell to cell; and this seems to be the case in those parts of the highest Animals, in which the vital changes are least active.

Action of the Heart.

480. The Heart is endowed in an eminent degree with the property of *irritability*, by which is meant the capability of being easily excited to movements of contraction alternating with relaxation (§ 366). Thus, after the Heart has been removed from the body, and has ceased to contract, a slight irritation will cause it to execute, not one movement only, but a series, gradually diminishing in vigour until they cease. To this property, the contact of blood with the membrane lining its cavity, appears to be the usual stimulus; and, when this is withdrawn, its action will cease after a certain time; whilst it may be prolonged, by means of artificial respiration (which assists in maintaining the circulation through the lungs), for a much greater duration, after the brain and spinal cord have been removed, when animal life is, therefore, completely extinct. The irritability of the heart is much less speedily lost in cold-blooded, than in warm-blooded animals; the heart of the frog, for example, will go on pulsating for many hours after its removal from the body; and it is stated by Dr. Mitchell,* that the heart of a sturgeon, which he had inflated with air, continued to beat, until the auricle had absolutely become so dry as to rustle during its movements. It is commonly supposed that, when it is empty of blood, the contact of air with its internal cavities is the stimulus by which the irritability is excited; but Dr. J. Reid has proved that this is not a sufficient explanation, by placing under an air-pump a frog's heart in a state of activity, which still continued after the receiver had been exhausted.† It is thought by Dr. Alison, that the succession of movements may be in some degree accounted for, by the peculiar arrangement of the fibres of the heart, which may cause one set, in contracting, to press on and irritate another; and this idea may be considered as by no means unworthy of adoption, although it can scarcely account for the whole of the phenomena. In all experiments made upon the cause of the heart's contraction, it must be carefully borne in mind, that the slightest disturbance of the organ will frequently renew its motions after they have ceased for some time; the neglect of which fact has led to several erroneous conclusions. It has been thought by some, that the contraction of the ventricle is the necessary sequence of the contraction of the auricle,—a doctrine which might seem to follow inevitably from the circumstance (ascertained by Dr. Knox) that, when the irritability is nearly exhausted, contractions excited in the auricle are sometimes followed by contractions of the ventricle, when irritation of the outer surface of the ven-

* American Journal of the Medical Sciences, vol. vii. p. 58.
† Cyclopædia of Anatomy and Physiology, vol. ii. p. 611.

tricle itself produced no effect. But it is to be remembered that the irritability of the internal surface is much greater than that of the external; and the movement of the auricle will excite that of the ventricle, by renewing the usual stimulus. That this is the true explanation is shown by the facts observed by Dr. Reid and others,—that the usual relation between the movements of the auricles and ventricles is often so much disturbed when the irritability is becoming exhausted, that these do not regularly alternate with each other,—that the contraction of the auricle frequently ceases before that of the ventricle, on the left side particularly,—and that both sets of movements will continue, when the auricle and ventricle have been separated from each other.

481. It was formerly supposed that the movements of the Heart were dependent upon its connection with the centres of the cerebro-spinal nervous system; and the experiments of Legallois and others, who found that they were arrested by crushing, or otherwise suddenly destroying, large portions of these centres, appeared to favour the supposition. But it has been shown by Dr. Wilson Philip and his successors in the same inquiry, that the whole cerebro-spinal axis might be *gradually* removed, without any such consequence; which fact harmonizes perfectly with the "experiments prepared for us by Nature," in the production of monsters destitute of these centres, which nevertheless possessed a regularly-pulsating heart. It has latterly been the fashion with many, however, to attribute the action of the heart to the ganglionic system; but of this there is no sufficient evidence. As has already been generally remarked on this subject, the *possibility* of exciting the action of the heart through the sympathetic nerve shows that this may have an influence on its movements; whilst the great difficulty with which any evidence to this effect can be procured, is in itself a sufficient proof, that this influence cannot be nearly adequate to the constant maintenance of this energetic function. It would appear, however, that changes in the ganglionic nerves, like strong impressions upon the cerebro-spinal system, may have the effect of impeding or even checking the heart's action; for a case has lately been recorded, in which the movements were occasionally checked for an interval of from 4 to 6 beats, its cessation of action giving rise to the most fearful sensations of anxiety, and to acute pain passing up to the head from both sides of the chest,—these symptoms being connected, as it proved on a post-mortem examination, with the pressure of an enlarged bronchial gland upon the great cardiac nerve.* It may be surmised that in many cases of angina pectoris, in which no lesion sufficient to account for death could be discovered, some affection of the cardiac plexus might have been traced on a more careful examination. It may be stated that Brachet has asserted, that, by section of the cardiac ganglion, he has caused the movements of the heart to be suddenly arrested; but this result has not been confirmed by other experimenters.

482. When the heart is exposed in a living animal, and its movements are attentively watched, they are seen to be of a peculiarly rhythmical character, one series following another with great regularity. In an active and vigorous state of the circulation, however, they are so linked together that it is not easy to distinguish them into periods. A case has recently fallen under the notice of Prof. Cruveilhier, in which the heart was exterior to the chest, having escaped from it by a perforation in the superior part of the sternum; and his observations upon it may be perhaps regarded as more

* Müller's Archiv. 1841, heft iii.; and Brit. and For. Med. Rev., Oct. 1841.

satisfactory, than such as are made after the very severe operation required for the artificial exposure of the organ; although they are liable to some exception from the very early age of the subject of them, which had only been born nine hours. His conclusions will be here adopted: with such additional remarks as are suggested by the experimental researches of others, who have made this question a subject of special attention. It is universally admitted that both auricles contract and also dilate simultaneously; and that both ventricles do the same:—also that the contraction or systole of the ventricles corresponds with the projection of blood into the arteries, causing the pulse; whilst the diastole or dilatation of the ventricles coincides with the collapse of the arteries. It is further admitted that the contraction of the ventricles, and that of the auricles, alternate with one another; each taking place (for the most part, at least,) during the dilatation of the other. But it is a question whether there is any interval between them. In the case just alluded to, the contraction of the ventricles is stated to have been precisely synchronous with the dilatation of the auricles, and the dilatation of the ventricles to have been performed at the same time with the contraction of the auricles, no period of repose intervening between the two sets of actions. It appears, however, from the concurrent testimony of numerous experimenters, that, whilst the contraction of the ventricle immediately succeeds that of the auricle, an interval, which is usually however extremely brief, may elapse between the partial dilatation of the ventricles and the succeeding systole of the auricles. The ventricular diastole may be distinguished into two stages, of which the first immediately succeeds its systole, and manifests itself in the recession of the heart's apex from the front of the chest; whilst the second is attended with an enlargement of the heart in all its dimensions, and is synchronous with the auricular contraction. It is between these two that the interval of repose occurs, where it can be observed. The following tabular view will, perhaps, make this account more intelligible; it is framed in such a manner as to commence with the auricular contraction; but, when considering the sounds of the heart, it will be necessary to commence with the ventricular systole.

Auricles.		*Ventricles.*
Contraction.		2d stage of dilatation.
Dilatation.		Contraction.—Pulse.
		1st stage of dilatation.
	Brief interval of Repose.	
Contraction.		2d stage of dilatation.
Dilatation.		Contraction.—Pulse.

483. The duration of the contraction of the ventricles is, according to Cruveilhier, double that of their dilatation; and the same holds good of the auricles. In the systole of the ventricles, their surface becomes rugous; the superficial veins swell; the carneæ columnæ of the left ventricle are delineated; and the curved fibres of the conical termination of the left ventricle, which alone constitutes the apex of the heart, become more manifest. During their contraction, the ventricles contract in every diameter; their shortening is the most sensible change; but this is owing to the vertical diameter being the greatest. The lower extremity of the left ventricle, or, in other words, the apex of the heart, describes a spiral movement from right to left, and from behind forwards. It is to this slow, gradual, and as it were successive spiral contraction, that the forward movement of the apex of the heart is owing, and the consequent percussion against the thoracic parietes. The ventricular systole is not accompanied by a projection of the

entire heart forwards (as some have maintained); for it is exclusively the spiral contraction, which determines the approach of the apex of the heart and the thoracic parietes. The diastole of the heart, according to Cruveilhier, has the rapidity and energy of an active movement, triumphing over pressure exercised upon the organ, so that the hand closed upon it is opened with violence. This is an observation of great importance; but of the cause to which this active dilatation is due, no definite account can be given. It may partly be explained, perhaps, by the elasticity of the tissue interwoven with muscular fibre in the substance of the heart; and this may be the cause of the first ventricular dilatation, the second being produced by the ingress of blood occasioned by the auricular systole. But the dilatation of the auricles appears to be much greater than can be accounted for by any *vis a tergo* (which, as will hereafter appear, is extremely small in the venous system,) or by the elasticity of its substance; for it was observed in this case to be so great, that the right auricle seemed ready to burst, so great was its distension, and so thin were its walls. Moreover, the large veins near the heart contract simultaneously with the auricular systole, and not with its diastole; so that they can have no influence in causing is dilatation. The ventricular diastole is accompanied with a projection of the heart downwards; this motion was at its maximum when the child was placed vertically, and was very strongly marked.

484. When the ear is applied over the cardiac region, during the natural movements of the heart, two successive sounds are heard, each pair of which corresponds with one pulsation. The whole interval between one beat of the heart and the next may be divided into four parts; of which the two first are occupied by what is commonly known as the *first* sound; the third, by the *second* sound; whilst the fourth is a period of repose. The first sound is dull and prolonged; it is evidently synchronous with the impulse of the heart against the parietes of the chest, and also with the pulse, as felt near the heart; it must, therefore, be produced during the ventricular systole. The second sound follows so immediately upon the conclusion of the first, that it can scarcely be imagined to take place during the auricular systole as some have supposed, but must be assigned to the period of the first stage of the ventricular diastole. This, indeed, may now be regarded as clearly established; for it has been fully demonstrated that the second sound is due to the sudden filling out of the semi-lunar valves of the aorta and pulmonary artery with blood, when the outward current through them has ceased, and the incipient dilatation of the ventricles occasions a vacuum behind them. If one of these valves be hooked by a curved needle against the side of the artery, so that a reflux of blood is permitted, the sound is entirely suppressed.

485. The first sound cannot be so readily or satisfactorily accounted for. That it is partly due to the impulse of the apex of the heart, seems proved by the fact, that, when this impulse is prevented, the sound is much diminished in intensity; and also by the circumstance, that, when the ventricles contract with vigour, the greatest intensity of the sound is over the point of percussion. But that it is not entirely due to this cause is also evident, from the fact that a sound may still be heard when the heart is contracting out of the body, as in the case observed by Prof. Cruveilhier. This sound has been attributed by some experimenters, to the flapping-back of the auriculo-ventricular valves; by others to the muscular contraction of the walls of the ventricles; by others again to the rush of blood along the irregular walls of the ventricles, and through the comparatively narrow orifices of the aorta and pulmonary artery. This last is probably the most con-

sistent with truth, as would appear from the following interesting observations made by Cruveilhier. By applying the finger to the origin of the pulmonary artery (which is situated in front of the aorta and completely conceals it), a perfectly distinct vibratory *fremissement*, corresponding with the ventricular diastole, was perceived; but no such vibratory thrill could be felt by the finger when applied to any part of the base of the ventricles; whence it was evident that no action takes place in the mitral and tricuspid valves, that can give rise to the same *palpable* effects as those produced by the semilunar valves. The same was ascertained regarding the valvular sound, which could be distinctly heard by laying the finger against the origin of the pulmonary artery, and applying the ear to it as to a stethoscope; whilst nothing of the kind could be perceived in the region of the auriculo-ventricular valves. Hence it seems quite certain that the natural first sound cannot be dependent in any way upon the action of the latter. It appeared, on the contrary, that the maximum intensity of the first sound was in precisely the same situation as the maximum intensity of the second, —namely, at the origin of the large arteries; and that it diminished as the ear was carried from the base towards the apex of the heart. Moreover, the first sound was observed to be of exactly the same character with the second (the complicating effect of the impulse being here withdrawn), except as to its intensity which was less, and its duration which was greater.

486. Hence, although these observations do not entitle us to deny the participation of the muscular contraction, and of the movement of the blood over the ventricular walls, in the production of the first sound, they clearly establish that the principal cause of it exists at the entrances to the arterial trunks; and it does not seem that any other reason can be assigned for it, than the prolonged rush of blood through their orifices, and the throwing-back of the semilunar valves, which, in suddenly flapping-down again, produce the second sound. That an exaggeration of the first sound, not essentially differing from it in character, is often produced by disease of the sigmoid valves, which causes an obstruction of their orifice, has long been known; and in such cases the character of the second sound is also changed. Indeed M. Cruveilhier states it as in his opinion an uniform occurrence, that disease of the semilunar valves alters both sounds. When this disease is such as to prevent the valves from effectually closing, a reflux of blood takes place into the ventricle at the time of its diastole, causing a rushing sound, more or less prolonged, to be heard in the intervals of the pulse, instead of with it. These considerations appear to prove almost incontestably, that the cause of the first sound, and that of the second, are very closely allied; and this view, which if correct is of great importance in the explanation of numerous morbid phenomena, harmonizes well with the known effect of a slight obstruction in a tube through which fluid is being rapidly forced, in producing a prolonged sound very analogous to the first sound of the heart. The following table may assist the learner in connecting the sounds of the heart with its movements.

FIRST SOUND.	Ventricular systole and auricular diastole. Impulse of apex against parieties of chest. Pulsation in arteries.
SECOND SOUND.	First stage of ventricular diastole.
INTERVAL.	Short repose; then auricular systole, and second stage of ventricular diastole.

487. The course of the circulating fluid through the Heart, and the action of its different valves, will now be briefly described. The venous blood which is returned by the ascending and descending vena cava, enters the

right auricle during its diastole; and, when it contracts, is forced between the mitral valves into the ventricle. The reflux of blood into the veins, during the auricular systole, is prevented by the valves with which they are furnished; but these valves are so formed as not to close accurately, especially when the tubes are distended, so that a small amount of reflux usually takes place, and this is much increased when there is any obstruction to the pulmonary circulation. Whilst the right ventricle is contracting upon the blood that has entered it, the carneæ columnæ, which contract simultaneously with its proper walls, put the chordæ tendineæ upon the stretch; and these draw the flaps of the tricuspid valve into the auriculo-ventricular axis. The blood then getting behind them, and being compressed by the contraction of the ventricle, forces the flaps together in such a manner as to close the orifice; but they do not fall suddenly against each other, as is the case with the semilunar valves, since they are restrained by the chordæ tendineæ; whence it is that no sound is produced by their closure. The blood is expelled by the ventricular systole into the pulmonary artery, which it distends, passing freely through the semilunar valves; but as soon as the *vis a tergo* ceases, and reflux might take place by the contraction of the arterial walls, the valves are filled out by the backward tendency of the blood, and completely check the return of any portion of it into the ventricle. The blood, after having circulated through the lungs, returns as arterial blood, by the pulmonary veins, to the left auricle; whence it passes into the left ventricle, and thence into the aorta, in the same manner with that on the other side, as just described.

488. There are, however, some important differences in the structure and functional actions of the two divisions of the heart, which should be here adverted to. The walls of the left ventricle are considerably thicker than those of the right; and its force of contraction is much greater. The following are the comparative results of M. Bizot's recent measurements, taking the average of males from 16 to 89 years. In the female, the

	Base.	Middle.	Apex.
Left Ventricle	$4\frac{1}{2}$ lines	$5\frac{1}{8}$ lines	$4\frac{3}{4}$ lines
Right Ventricle	$1\frac{1}{16}$ lines	$1\frac{3}{8}$ lines	$1\frac{1}{30}$ lines

average thickness is somewhat less. It will be seen that the point of greatest thickness in the left ventricle is near its middle, while in the right it is nearer the base. The thickness of the former goes on increasing during all periods of life, from youth to advanced age, whilst that of the right is nearly stationary. The left auricle is somewhat thicker than the right; the average thickness of the former being, according to Bouillaud, a line and a half, whilst that of the latter is only a line. In regard to the relative capacities of the right and left cavities, much difference of opinion has prevailed. The right auricle is generally allowed to be more capacious than the left; and the same is commonly taught of the right ventricle. So much fallacy may arise, however, from the peculiar condition of the animal at the moment of death, that this is not easily proved, and is indeed by no means certain. Many eminent anatomists maintain that the two cavities are equal. The capacity of each of the cavities may be estimated in the full-sized heart, at about two ounces; that of the auricles being probably a little less, and that of the ventricles a little greater. That the ventricles receive more blood from the auricles than the latter could transmit to them by once emptying themselves, seems therefore probable; and may be accounted for by the fact already stated, regarding the slight intermission in the ventricular diastole, during which more blood may enter the auricle from the veins.

489. There is a well-known anatomical difference between the auriculo-ventricular valves on the two sides, which has given rise to the diversity of name. This seems, from the researches of Mr. King,* to be connected with an important functional difference. The mitral valve closes much more perfectly than the tricuspid; and the latter is so constructed, as to allow of considerable reflux, when the cavities are greatly distended. Many occasional causes tend to produce an accumulation of blood in the venous system, and in the left side of the heart; thus, any obstruction to the pulmonary circulation, cold, compression of the venous system by muscular action, &c., are known to favour such a condition. This is a state of peculiar danger, from the liability which over-distension of the ventricular cavity has to produce a state of muscular paralysis; and in the structure of the heart itself there seems to be a provision against it. For, when the ventricle is thus distended, the tricuspid valves do not close properly, and a reflux of blood is permitted; not only into the auricle, but also (through the imperfect closure of their valves under the same circumstances) into the large veins. This is proved by the fact, several times observed by Dr. J. Reid in his experiments upon Asphyxia, &c., that when the action of the right ventricle had ceased from over-distension, he could frequently re-excite it, not merely by puncturing its walls, but by making an opening in the jugular vein. This fact evidently affords an indication of great importance in the treatment of Asphyxia; and it explains the reflux of blood, or *venous pulse*, which is frequently observed in cases of pulmonary disease, and which, according to Mr. King, always exists in a less striking degree.

490. It is not quite certain whether the ventricles empty themselves completely at each contraction; but it seems probable that the blood which they contain is not entirely forced into the arteries. The quantity which is propelled by each ventricle, at every stroke, may be estimated, therefore, at from 1½ oz. to 2 oz. If we adopt the lower of these numbers, we shall find that, reckoning 75 pulsations of the heart to a minute, 112 oz. or 7 lbs. of blood pass through each ventricle in that time; and, on the higher one, 150 oz. or 9 lbs. 6 oz. would pass through in the same period. Now the whole quantity of blood contained in the human body, according to the estimate of Haller, (which is considered by Dr. Allen Thomson to be near the truth,) is about one-fifth of the weight of the body, or 28 lbs. in a person weighing 140 lbs.† This quantity would pass through the heart, therefore, in four minutes, on the lower of the two preceding estimates, or in three minutes on the higher; and would circulate afresh, therefore, fifteen or twenty times in an hour. It would appear, however, that this estimate of the rapidity of the circulation is very far from the truth; for recent experiments have shown that substances introduced into the venous circulation may be detected in the remotest parts of the arterial circulation, even in animals larger than Man, in less than half a minute. The earliest of such experiments were those of Hering,‡ who endeavoured to ascertain the rapidity of the circulation, by introducing prussiate of potash into one part of the system, and drawing blood from another. He states that he detected this salt in blood drawn from one of the jugular veins of the horse, within 20 or 30 seconds after it had been introduced into the other; in which brief space the blood must have been received by the heart, must have been

* Guy's Hospital Reports, Vol. II.
† Cyclopædia of Anatomy, Art. Circulation. See also § 581.
‡ Tiedemann's Zeitschrift, Vol. III. p. 85.

transmitted through the lungs, have returned to the heart again, have been sent through the carotid artery, and have traversed its capillaries. From experiments of a similar nature upon other veins, he states that the salt passed from the jugular vein into the saphena in 20 seconds; into the masseteric artery in from 15 to 20 seconds; into the external maxillary artery in from 10 to 25 seconds; and into the metatarsal artery in from 20 to 40 seconds. An attempt has been made to invalidate the inference which seems inevitably to flow from these experiments, in regard to the rate of the circulation, by attributing the transmission of the salt to the permeability of the animal tissues;* but it has never been shown that even prussiate of potash (which is probably more transmissible through this channel than is any other salt) can be carried from one part to another with a rapidity at all proportional to this. The only mode in which this property can be conceived materially to facilitate the transmission of the salt through the vascular system, would be by allowing it to pass through the septum of the auricles, and thus to make its way from the right to the left side of the heart, without passing through the pulmonary circulation; and this it could scarcely do, to the large amount which is evidently transmitted, in so short a time.

491. The experiments of Hering have recently been fully confirmed by those of Mr. Blake;† who varied them by employing different substances, and took other precautions against sources of fallacy. Ten seconds after having injected a solution of nitrate of baryta into the jugular vein of a horse, he drew blood from the carotid artery of the opposite side; after allowing this to flow for five seconds, he substituted another vessel, which received the blood that flowed during the five ensuing seconds; and the blood that flowed after the twentieth second, by which time the action of the heart had stopped, was received into a third vessel. These different specimens were carefully analyzed. No trace of baryta could be detected in the blood which had escaped from the artery between the tenth and fifteenth second after the injection of the poison; but in that which was drawn between the fifteenth and the twentieth second, the salt was found to be present, and in greater abundance than in the blood which had subsequently flowed. Moreover, the coincidence between the cessation of the heart's action, and the diffusion of the salt through the arterial blood, bear a striking correspondence; and it may be hence inferred, that the arrestment of its muscular movement is due to the effect of this agent upon its tissue, when immediately operating upon it, through the capillaries of the coronary artery. This conclusion is borne out by a variety of other experiments, which show that the time of the agency of other poisons that suddenly check the heart's action (which is the especial property of *mineral* poisons) nearly coincides, in different animals, with that which is required to convey them into the arterial capillaries. And it seems to derive full confirmation from the fact, that poisons which act locally on other parts, give the first indications of their operation in the same period after they have been introduced into the venous circulation. Thus, in the Horse, the time that is required for the blood to pass from the jugular vein into the capillary terminations of the coronary arteries is 16 seconds, as is shown by the power of nitrate of potass to arrest the heart's action within that time; and nitrate of strychnia, injected into a vein, gave the first manifestation of its action on the spinal cord in precisely the same number of seconds.

* See Dr. Allen Thomson, *loc. cit.*
† Edinb. Med. and Surg. Journal, Oct. 1841.

In the Dog, the heart's action was arrested by the nitrate of potass in 11 or 12 seconds; and the tetanic convulsions occasioned by strychnia also commenced in 12 seconds. In the Fowl, the former period was 6 seconds, and the latter 6½; in the Rabbit, the first was 4, and the other 4½ seconds. From these experiments it seems difficult to resist the conclusion, that the rapidity of the circulation is very much underrated in any estimate that we found upon the capacity of the heart, and its number of pulsations in a given time; and that some other force than its contractions must have a share in producing the movement of the blood through the vessels.

492. The force with which the Heart propels the blood may be estimated in two ways,—either by ascertaining the height of the column of that fluid, which its contractile action will support, or by causing the blood to act upon a shorter column of mercury. The former method was the one adopted by Hales, who introduced a long pipe into the carotid artery of a horse, and found that the blood would sometimes rise in it to the height of 10 feet. From parallel experiments upon sheep, oxen, dogs, and other animals, and by comparing the calibre of their respective vessels with that of the Human aorta, Hales concluded that the usual force of the heart in Man would sustain a column of blood 7½ feet high, the weight of which would be about 4 lbs. 6 oz. The second method is that more recently adopted by Poisseuille; and the instrument which he contrived for carrying it into practice (termed by him the Hæmadynamometer) has been the means of aiding many valuable inquiries on the physiology of the circulation. The result of his experiments is very nearly the same as that of Hales; his estimate of the force with which the blood is propelled into the aorta being 4 lbs. 3 oz. The backward pressure upon the walls of the heart, or in other words the force which they have to overcome in propelling the blood, is properly estimated, by multiplying the pressure of blood in the aorta, into the surface of a plane passing through the base and apex of the left ventricle; by which calculation it is found to be about 13 lbs.* The pressure appears, from the experiments of Poisseuille, to be very nearly equal for equal surfaces, throughout the larger arterial branches, since it diminishes regularly in proportion to their calibre; in the radial artery at the wrist it was estimated by him at 4 drachms.

493. The number of contractions of the Heart in a given time is liable to great variation, within the limits of ordinary health, from several causes; the chief of these are, diversities of age, of sex, of muscular exertion, of the condition of the mind, of the state of the digestive system, and of the period of the day. Putting aside the other causes of uncertainty, the following table may be regarded as an approximation to the average frequency of the pulse, at the several ages specified in it.

	Beats per minute.
In the fœtus in utero - -	140 — 150
Newly-born infant - - -	130 — 140
During the first year - -	115 — 130
During the second year - -	100 — 115
During the third year - -	90 — 100
About the seventh year - -	85 — 90
Age of puberty - - -	80 — 85
Manhood - - -	70 — 80
Old age - - -	50 — 65

* The extreme latitude of the estimates which have been made of this force, has been a subject of not undeserved ridicule. Borelli imagined it to be 180,000 lbs; whilst by Keill it was supposed to be no more than from 5 to 8 ounces.

The difference caused by *sex* is very considerable, especially at adult age; it appears from the inquiries of Dr. Guy,* that the pulse of the adult female exceeds in frequency the pulse of the adult male at the same mean age, by from 10 to 14 beats in a minute. The effect of *muscular exertion* in raising the pulse is well known; as is also the fact, which is one exemplification of it, that the pulse varies considerably with the posture of the body. The amount of this variation has been made the subject of extensive inquiry by Dr. Guy; and the following are his results. In 100 healthy males, of the mean age of 27 years, in a state of rest, the average frequency of the pulse was, when standing, 79,—when sitting, 70,—and when lying, 67 per minute. Several exceptions occurred, however, to the general law; and when these were excluded, the average numbers were,—standing, 81,—sitting, 71,—and lying, 66; so that the difference between standing and sitting was 10 beats, or $\frac{1}{8}$ of the whole; the difference between sitting and lying was 5 beats or $\frac{1}{13}$th of the whole; and the difference between standing and lying was 15 beats, or ^{1}th of the whole. In 50 healthy females, of the same mean age, the average pulse when standing was 89,—when sitting, 81,—and when lying 80. When the exceptions (which were more numerous in proportion than in males) were excluded, the averages were, —standing, 91,—sitting, 84,—lying, 79; the difference between standing and sitting was thus 7 beats, or $\frac{1}{13}$th of the whole; that between sitting and lying was 4, or $\frac{1}{21}$st of the whole; and that between standing and lying was 11, or $\frac{1}{8}$th of the whole. In both sexes the effect produced by change of posture increases with the usual frequency of the pulse; whilst the exceptions to the general rule are more numerous as the pulse is less frequent. The variation is temporarily increased by the muscular effort involved in the absolute change of the posture; and it is only by the use of a revolving board, by which the position of the body can be altered without any exertion on the part of the subject of the observation, that correct results can be obtained. That the difference between standing and sitting should be greater than that between sitting and lying, is just what we should expect, when we compare the amount of muscular effort required in the maintenance of the two former positions respectively.

494. The pulse is well known to be much accelerated by mental excitement, especially by that of the emotions; it is also quicker during digestion; but on neither of these points can any exact numerical statement be given. The *diurnal* variation of the pulse, however, has been made the subject of observation by Dr. Guy;† and, as the results of his inquiries have much interest, although (from having been made only on his own person) they may ultimately require some modification, they will be here stated. "1. The pulse of a healthy male in a state of rest, unexcited either by food or exercise, is most frequent in the morning, and gradually diminishes as the day advances. 2. The pulse diminishes in frequency more rapidly in the evening than in the morning. 3. The diminution in the frequency of the pulse (after excitement) is more regular and progressive in the evening than in the morning. 4. The effect of food is greater and more lasting in the morning than in the evening; and in some instances, the same food which in the morning produces an effect considerable both in amount and duration, has no effect whatever in the evening." It may be hoped that, ere long, this interesting and important subject will receive further elucidation.

* Guy's Hospital Reports, Vol. III. p. 312.
† Op. cit. Vol. IV. p. 69.

Causes influencing the Circulation in the Arteries and Capillaries.

495. That the movement of the blood through the arterial trunks and the capillary tubes is, in Man and in other warm-blooded animals, chiefly dependent upon the action of the heart, there can be no doubt whatever. It can be easily shown by experiment that, if the arterial current be checked, the capillaries will immediately cease almost entirely to deliver the blood into the veins, and the venous circulation will be instantaneously arrested. But there are certain "residual phenomena" even in Man, which clearly indicate that this is not the whole truth; and that the blood-vessels have a considerable influence in producing both local and general modifications of the effects of the heart's action. There are also indications of the existence of an influence, in which the blood-vessels do not partake, arising from those changes occurring between the blood and the tissues, that constitute the processes of nutrition, secretion, &c. Such, for instance, would appear to be the interpretation of the fact that, whilst any variations in the action of the heart affect the whole system alike, there are many variations in the circulation, which, being quite local in their extent, cannot be attributed to such central disturbances, and must therefore be dependent on causes purely local. Of the nature of these influences, and of the mode of their operation, we shall probably arrive at a more correct knowledge if we examine the phenomena of the circulation in those beings in which the moving power is less concentrated than it is in the higher Animals; for just as we find in the latter that the development of special absorbent vessels does not exclude the function of absorption from being still performed by the general vascular system (§ 459), so may we here be led to perceive, that there is a generally-diffused force, to which alone the circulation of the nutritious fluid in the lowest organisms is due, and which is not altogether replaced by the special organ of impulsion developed in the centre of the system in the higher.

496. The ascent of the sap in Vegetables is probably to be regarded as due in part to the *vis a tergo* occasioned by the action of Endosmose at the roots; and in part to the demand for fluid occasioned by the vital processes taking place in the leaves. For, if the stem of a vine, in which the sap is rising, be cut across, the sap will continue for some time to flow from the top of the lower portion; and its force of ascent may be shown to be very considerable, by tying over the cut surface a piece of bladder, which will be speedily burst,—or by affixing to it a bent tube, containing a column of mercury, which will be raised to the height of forty inches or more. On the other hand, the attractive force of the leaves is shown by the fact, that, if the lower end of the upper division be put into water, it will continue to absorb, as long as the vital actions of the leaves are being performed with vigour; but, if the branch be carried into a dark room, the exhalation from the leaves is immediately checked, and absorption is checked also. The influence of the actions at the periphery of the circulating system in maintaining the flow of fluid towards the part, is further shown by the fact, that, if a shoot of an evergreen species be grafted on a stock of one with deciduous leaves, a continual and unwonted ascent of sap will be kept up in the latter through the winter; this being evidently due to the demand occasioned at its summit. Again, the recommencement of the annual flow of sap in an ordinary tree, has been found to take place in the first instance, not at its roots, but in the neighbourhood of the buds; for their expansion, under the influence of the returning warmth, exhausts the fluid from the vessels of their neighbourhood; this, again, occasions a demand from below: and thus

the motion is gradually propagated to the roots. Now it has been experimentally ascertained that, if a branch of a vine growing in the open air be trained into a hot-house, it may be made to vegetate during the winter, and to draw up fluid through the stems and roots whose condition has not been changed. It is evident, then, that in Plants the demand for fluid in the organs to which it is distributed by the vascular system, is one of the chief forces by which the supply is obtained.

497. This is still more evidently the case in regard to the circulation of nutritious or elaborated sap, which takes place in the under surface of the leaves and in the bark. The object of this movement is not to convey the fluid in a direct line from one point to another (as is the case with the ascending current) but to supply every part with materials for its growth, or for the production of its peculiar secretions. Hence the vessels in which it takes place form a minutely-anastomosing network; instead of consisting of a system of straight and distinct tubes. Through this network, the latex or elaborated sap is seen to move, exactly as does the blood through the capillary vessels of animals. The movement takes place, under favourable circumstances, with considerable rapidity; it is accelerated by heat, and retarded by cold; and it is subject to all those minor irregularities (such as the cessation of movement, or change in the direction of the current, in a particular channel), which are so constantly to be noticed by any one who attentively watches the capillary circulation of animals, and which clearly prove the operation of some causes independent of the heart's action. The general direction of the elaborated sap, through this capillary system, is downwards; but that the force of gravity cannot have much to do with the movement, is shown by the fact that, in a dependent branch, it has to *ascend* towards the stem, which it will do without interruption from this cause.

498. In the lowest Animals, the movement of the circulating fluid seems as independent of any central organ of impulsion, as it has been shown to be in Plants. Thus in the living Sponge, a current of water is continually flowing through the tubes and channels by which its substance is traversed, the fluid being taken in by the small orifices, and ejected in powerful streams from the large ones; and yet the most attentive examination has not revealed any mechanical cause for this movement. In some of the compound Polypifera, a similar current may be seen; and it is curious that, in many species, its direction undergoes a periodical change, being reversed at intervals of a certain number of seconds. In the Star-Fish and Sea-Urchin tribe, a complex circulation of blood takes place, through regular vessels; and here we find some indication of a contractile cavity, by the power of which it may be, in some degree, kept up; but its feeble pulsations can scarcely be regarded as having any great share in the movement of the fluid which passes through it. In the Articulated series there is, with a few exceptions, an absence of any central organ of impulsion, possessed of power sufficient to carry the blood through the vascular system by its contractions alone. In many of the aquatic worms and larvæ, the movement of the blood, and the pulsations of the dorsal vessel, may be distinctly seen; and the thinness of the walls of the latter, and the character of its movements, seem clearly to show, that these can scarcely be regarded as propulsive, but that they merely result from the variations in the current which passes through it,—the sides flapping together when there is an outward flow, and bulging out when there is an influx. It is in those Articulata, in which there is a provision for respiration throughout the whole structure, as is especially the case in Insects, that the absence of any central impulsive

power is most remarkable. In the Crustacea, as in the Mollusca in general, the respiration is aquatic, and is restricted to a particular organ; and in these, the heart is found to be more muscular, and the circulation to be more under its control, than in the rest of the group. It is curious to remark, however, that, in some of the lower Mollusca, which exhibit a tendency to aggregation into compound structures, like those of the Polypifera, there is the same want of definiteness in the course of the circulation, as has been just stated to exist in the latter group,—the flow of blood through their complex apparatus of nutritive organs being arrested at regular intervals, and then recommencing in the reverse direction.

499. Even in Vertebrated animals, we find indications of the same deficiency of central power over the peripheral circulation. When we look at the simple, thin-walled heart of Fishes, for example, it seems impossible that it should have much power over the current of blood flowing back to it by the veins; for of this blood, a considerable portion has to pass through three sets of capillaries, between its ejection from the heart, and its return to it. It is first transmitted through the respiratory capillaries, for the purpose of aeration; the confluent vessels, which collect the blood from these, terminate in the general systemic trunk or aorta, in which, as in the veins of man, there is an absence of pulsation, and by these it is distributed to the systemic capillaries; and the blood which, after passing through these, returns from the posterior part of the body, and from the viscera, passes through another set of capillaries, those of the liver and kidneys, before it returns to the heart. Even in the warm-blooded Vertebrata, in which the respiratory circulation is separately performed, the blood which is returned from the intestines passes into a trunk, the vena porta, which again subdivides into capillary ramifications, being transmitted over the plexus of biliary ducts, of which the liver is chiefly composed; and thus the vena porta, as Hunter justly observed, should be considered rather in the light of an artery,* resembling as it does the aorta of Fishes. Considering the small amount of pressure which is exerted by the blood upon the sides of the vessels that are formed by the reunion of capillaries, it seems impossible to imagine that the *vis a tergo*, derived from the impulsive action of the heart, can be alone sufficient to maintain the portal circulation.

500. We have next to consider the influence of the arterial tubes, on the flow of blood through them. This influence is exerted by the middle or fibrous coat, which alone is possessed of contractile properties. This coat consists of a network of interlaced fibres, possessing no small resemblance to that, of which the muscular coat of the alimentary canal is composed. It cannot be said that its structure corresponds with that, which we are accustomed to regard as characteristic of muscle; but its properties seem clearly analogous with those of that tissue. These properties we must distinguish into the simple *elasticity*, which merely depends upon the molecular arrangement of the particles composing the fabric, and persists after death, until a serious change takes place in their composition; and that *contractility* on the application of a stimulus, which is characteristic of a structure possessed of vitality, and departs when that is lost. There is some reason for believing, that these two properties are the endowments of distinct structures, and that the one or the other may predominate in the several parts of the arterial system. Thus, it was justly remarked by Hunter, that elasticity, being the property by which the interrupted force

* That it conveys venous blood, is no reason to the contrary; since this is the case with the pulmonary artery. The character of an artery is derived from the division of its current into several diverging streams.

of the heart is made equable and continuous, is most seen in the large vessels more immediately connected with that organ. On the other hand, there seems good ground for the assertion, that the contractility, which is the endowment of something analogous to muscular structure, is most observable in the smaller vessels, where it is more required for regulating the flow of blood towards particular organs.

501. It is easily shown that the action of the elasticity of the arterial tubes is one of a purely physical character; and that its purpose is to convert the intermitting impulses which the fluid receives from the heart, into a continuous current. The former are very evident in the larger trunks; but they diminish with the subdivision of these, until they entirely disappear in the capillaries, in which the stream is usually equable or nearly so. We may imagine a powerful forcing-pump injecting water, by successive strokes, into a system of tubes with unyielding walls;—the flow of fluid at the farther extremities of these tubes would be as much interrupted as its entrance into them. But if an air-vessel (like that of a fire engine) were placed at their commencement, the flow would be in great degree equalized; since a part of the force of each stroke would be spent upon the compression of the air included in it, and this force would be restored by the elasticity of the air during the interval, which would propel the stream until directly renewed by the next impulse. A much closer imitation of the natural apparatus would be afforded by a pipe which had elastic walls of its own; if water were forced by a syringe into a long tube of caoutchouc, for example, the stream would be equalized before it had proceeded far. This effect is found to be accomplished at any point of the arterial circulation, in a degree proportionate to its distance from the heart; and it is another effect of the same cause, that the pressure of the blood upon the walls of the arteries (as shown by the experiments of Poisseuille) is nearly the same all over the system. It is to the distension of the arterial tubes, both in their length and calibre, that their pulsation is due. Their elongation is the more considerable of the two effects; and it causes the artery to be lifted from its seat and to become curved. The transverse dilatation has been denied by some physiologists; but it has been recently proved to take place, by an ingenious experiment of Poisseuille's. The increase of capacity, however, is not more than one-tenth; so that the increase of diameter will not be so much as one-twentieth,—a quantity scarcely perceptible to ordinary measurement. The transmission of the pulse-wave through the whole system is not instantaneous, but takes place in an appreciable time. The pulsation of the large arteries near the heart is synchronous with the ventricular systole; but that of other arteries is somewhat later, the difference varying with their distance, and amounting in some instances to between one-sixth and one-seventh of a second.

502. It has been denied by many physiologists, that the middle coat of the arteries possesses any property which can be likened to muscular contractility; and it will therefore be desirable to enter somewhat in detail into the question. That it cannot be readily stimulated to contraction through the medium of its nerves, is universally admitted; but the same is the case in regard to the muscular coat of the alimentary canal, which contracts most vigorously on the direct application of stimuli to itself; and Valentin and others have recently succeeded in producing evident contractions in both, by irritation of the sympathetic nerve and of certain roots of the spinal nerves (§ 209). Further, although many experimenters have failed in producing contractions of this tissue by stimuli directly applied to itself, yet others have distinctly witnessed them; and, in any question of this kind, the

positive evidence must be held to outweigh the negative. Thus Verschuir states that he has seen arteries contract when stimulated by the mineral acids, by electricity, and by the application of the point of a scalpel. Dr. Thomson also saw them contract on the application of ammonia, and when punctured with the point of a fine needle in the living body. The exposure of arteries to the air was found by Hunter to occasion their contraction to such an extent, that obliteration of their tube was the result; and this statement has been subsequently confirmed. Further, every surgeon knows that the contraction of divided arteries is an efficient means of the arrest of hemorrhage from them, especially when they are of small calibre; so that, in the case of the temporal artery, for example, the complete division of the tube is often the readiest means of checking the flow of blood from it, when it has been once wounded. This contraction is much greater than could be accounted for by the simple elasticity of the tissue, and is more decided in small than in large vessels.

503. It has been ascertained by the direct and careful experiments of Poisseuille, that, when the artery is dilated by the blood injected into it from the heart, it reacts with a force superior to the impressing impulse; and he has also shown that, if a portion of an artery from an animal recently dead (in which the vital contractility seems to be preserved), and one from an animal that has been dead some days (in which nothing but the elasticity remains), be distended with an equal force, the former becomes much more contracted than the latter, after the distending force is removed. Several experiments also indicate the existence of a power of slow contraction in the arteries, which has been distinguished by the appellation *tonicity;* but which does not seem any thing else than a particular manifestation of the general property of vital contractility, and is certainly of a nature quite distinct from ordinary elasticity. Thus, when a ligature is placed upon an artery in a living animal, the part of the artery beyond the ligature becomes gradually smaller, and is emptied to a certain degree, if not completely, of the blood it contained. Again, when part of an artery in a living animal is isolated by means of two ligatures, and is punctured, the blood issues from the orifice, and the enclosed portion of the artery is almost completely emptied of its contents. The empty condition of the arteries generally found within a short time after death seems to be in part due to the same cause; since their calibre is usually much diminished, and is sometimes completely obliterated. A remarkable example of the same slow contraction, is that which takes place in the end of the upper portion of an arterial trunk, when the passage of blood through it is interrupted by a ligature; for the current of blood then passes off by the nearest large lateral branch; and the tube of the artery shrivels, and soon becomes impervious, from the point at which the ligature is applied, back to the origin of that branch. This last fact is important, as proving how little influence the *vis a tergo* possesses over the calibre of arterial tubes; since, without any interruption to the pressure of blood occasioned by it, the tube becomes impervious.

504. It is still to be inquired, in what manner this contractility of the arteries is to be regarded as influencing the flow of blood through them. It is at once evident that any *general* contraction of the arterial tubes would have rather the effect of opposing an obstacle, than of assisting the flow; but if the fibrous coat of the arteries is in some degree disposed to the alternate contraction and relaxation which is so remarkable in the heart, they *may* exert a force which shall be supplementary to that of the heart's impulse,—relaxing to receive the blood from it, and contracting upon their contents, with a power superior to that by which they were distended. It

is difficult to say whether or not this be the case, though there would certainly appear some evidence in favour of the supposition. The loss of the heart's power over the currents of blood, in proportion to their degree of subdivision through the increased friction to which they will be subjected, would seem to require some compensating power, in order that the perfect equality of pressure may be obtained, which has been spoken of as existing in all parts of the arterial system. In no other way than this can the fibrous coat of the arteries be regarded as having any propulsive power over their contents, except by a peristaltic or vermicular movement, resembling that which takes place in the alimentary canal; and of such there is no evidence whatever. A very important use may be assigned to this muscular coat, which has been generally overlooked by physiologists,—that of *regulating* the diameter of the tubes, in accordance with the quantity of blood to be conducted through them to any part; which will depend upon its peculiar circumstances at the time. Such local changes are continually to be observed, in the various phases of normal life, as well as in diseased states; and they will be found to be constantly in harmony with the particular condition of the processes of nutrition, secretion, &c., to which the capillary circulation ministers. Of this kind are the enlargement of the trunks of the uterine and mammary arteries, at the epochs of pregnancy and lactation;—the enlargement and strongly-increased pulsation of the radial artery, when there is any active inflammation in the thumb;—the enormous diameter which the spermatic artery will attain, when the testicle is greatly increased in size by diseased action; and many other similar phenomena. In such cases, it cannot be the action of the heart that increases the calibre of the vessels; since this is commonly unaltered, and is itself unable, as we have just seen, even to maintain their permeability. It must, therefore, be by a power inherent in themselves, that their dilatation is effected. The minute distribution of the sympathetic nerve upon the walls of the arteries, the known power which this has of producing contractions alike in their fibrous coat and in the muscular tunic of the intestinal canal, and various phenomena which indicate the power of certain states of mind over the dimensions of the arteries, in particular parts of the body at least, render it highly probable that the calibre of the arteries is regulated in no inconsiderable degree through its intervention.* The *permanent* dilatation, however, which is seen in the arteries supplying parts that are undergoing enlargement, must be due not to simple dilatation merely, but to increased nutrition; since we find that their walls are thickened as well as extended. And, on the other side, when slow contraction occurs in these tubes as a consequence of their disease, it must be in part occasioned by atrophy; since their nutrition is so much diminished, that in time they almost entirely disappear,—a portion of a large artery occasionally shrivelling into a ligamentous band.

505. We now come to the last head of the inquiry into the powers which convey the blood through the capillary system,—that, namely, which concerns the agencies existing in the capillaries themselves. Many discussions on this subject may be found in physiological writings, and it has a bearing so immediate on one of the most important questions in Pathology,—the nature of inflammation,—that it deserves the fullest attention. The chief question in debate is the degree in which the capillary circula-

* For anatomical evidence to this effect, see Henle on the Contractility of the Blood-vessels, in Casper's Wochenschrift, May, 1840, and Brit. and For. Med. Rev. vol. x. p. 551.

tion is influenced by any other agency than the contractile power of the heart and arterial system;—some physiologists maintaining that this alone is sufficient to account for all the phenomena of the capillary circulation; —and others asserting that it is necessary to admit some supplementary force, which may be exerted either to assist, retard, or regulate the flow of blood from the arteries into the veins. We shall first inquire what evidence there is of the existence of any such force; and, when led to an affirmative conclusion, we shall examine into its nature. No physiological fact is more clearly proved, than the existence, in the lower classes of Animals, as well as in Plants, of some power independent of a *vis a tergo*, by which the circulating fluid is caused to move through their vessels. This power seems to originate in themselves, and to be closely connected with the state of the nutritive and secreting processes; since any thing which stimulates these to increased energy accelerates the circulation, whilst any check to them occasions a corresponding stagnation. It may be convenient to designate this motor force by the name of *capillary power*; it being clearly understood, however, that no mechanical propulsion is thence implied. On ascending the Animal scale, we find the power which, in the lower organisms, is diffused through the whole system, gradually concentrated into a single part,—a new force, that of the heart, being brought into operation, and the circulation placed, in a greater or less degree under its control. Still there is evidence that the movement of blood through the capillaries is not entirely due to this; since it may continue after the cessation of the heart's action, may itself cease in particular organs when the heart is still acting vigorously, and is constantly being affected in amount and rapidity by causes originating in the part itself, and in no way affecting the heart. The chief proofs of these statements will now be adverted to.

506. The movement of the blood in the capillaries of cold-blooded animals, after complete excision of the heart, has been repeatedly witnessed. In warm-blooded animals this cannot be satisfactorily established by experiment, since the shock occasioned by so severe an operation much sooner destroys the general vitality of the system; but it may be proved in other ways to take place. After most kinds of natural death, the arterial system is found, subsequently to the lapse of a few hours, almost or completely emptied of blood; this is partly, no doubt, the effect of the tonic contraction of the tubes themselves; but the emptying is commonly more complete than could be thus accounted for, and must therefore be due to the continuance of the capillary circulation. Moreover, when death has taken place suddenly from some cause, (as, for instance, a sudden electric shock,) that destroys the vitality of the whole system at once, the arterial tubes are found to contain their due proportion of blood. Further, it has been well ascertained, that a real process of secretion not unfrequently continues after general or somatic death; urine has been poured out by the ureters, sweat exuded from the skin, and other peculiar secretions formed by their glands; and these changes could not have taken place unless the capillary circulation were still continuing. In the early embryonic condition of the highest animals, the movement of blood seems to be unquestionably due to some diffused power, independent of any central impulsion; for it may be seen to commence in the vascular area, before the development of the heart; the first movement is towards instead of from the centre; and even for some time after the circulation is fairly established, the walls of the heart consist merely of vesicles loosely attached together, and can hardly be supposed to have any great contractile power.

507. The last of these facts may be said not to have any direct bearing on the question, whether the capillary power has any existence in the adult condition; but the phenomena occasionally presented by the fœtus at a later stage appear decisive. Cases are of no very unfrequent occurrence, in which the heart is absent during the whole of embryonic life, and yet the greater part of the organs are well developed. In most or all of these cases, however, a perfect twin fœtus exists, of which the placenta is in some degree united with that of the imperfect one; and it has been customary to attribute the circulation in the latter to the influence of the heart of the former, propagated through the placental vessels. This supposition has not been disproved (however improbable it might seem) until recently; when a case of this kind occurred, which was submitted to the most careful examination by an accomplished anatomist;* and this decisive result was obtained,—that it seemed impossible that the heart of the twin fœtus could have occasioned the movement of blood in the imperfect one; and that some cause present in the latter must have been sufficient for the movement of blood through its vessels. It was a very curious anomaly in this case, that the usual functions of the arteries and veins must have been reversed; for the vena cava receiving its blood from the umbilical vein nearly as usual, had no communication with the arterial system (the heart being absent), except through the systemic capillaries, to which, therefore, the blood must have next proceeded, returning to the placenta by the umbilical artery. This view of the course of the blood was confirmed by the fact, that the veins were everywhere destitute of valves. It is evident that a single case of this kind, if unequivocally demonstrated, furnishes all the proof that can be needed of the existence, even in the highest animals, of a capillary power, which, though usually subordinate to the heart's action, is sufficiently strong to maintain the circulation by itself, when the power of the central organ is diminished. In this, as in many other cases, we may observe a remarkable power in the living system to adapt itself to exigencies. In the acardiac fœtus, the heart is never evolved; and the capillary power supplies its place up to the period of birth, after which, of course, the circulation ceases for want of due aeration of the blood. It has occasionally been noticed that a gradual degeneration in the structure of the heart has taken place during life, to such an extent that scarcely any muscular tissue could at last be detected in it; without any such interruption to the circulation as might have been anticipated.

508. It is equally capable of proof, on the other hand, that the capillaries may, by an influence peculiar to them, afford a complete check to the circulation in the part, even when the heart's action is unimpaired, and no mechanical impediment exists to the transmission of blood. Thus, cases of spontaneous gangrene of the lower extremities are of no unfrequent occurrence, in which the death of the solid tissues is clearly connected with a local decline of the circulation; and in which examination of the limb after its removal, shows that both the larger tubes and the capillaries were completely pervious; so that the cessation of the flow of blood could not be attributed to any impediment, except that arising from the cessation of some power which exists in the capillaries, and is necessary for the maintenance of the current through them. The most remarkable evidence on this point, however, is derived from the phenomena of Asphyxia, which will be more fully explained in the succeeding chapter. At present it may be stated as a fact, which has now been very satisfactorily ascertained, that, if admission

* See Dr. Houston in the Dublin Medical Journal, 1837.

of air into the lungs be prevented, the circulation through them will be brought to a stand, as soon as the air which they contain has been to a great degree deprived of its oxygen, or rather has become loaded with carbonic acid; and this stagnation will, of course, be communicated to all the rest of the system. Yet, if it have not continued sufficiently long to cause the loss of vitality in the nervous centres, it may be renewed by the admission of air into the lungs. Now, although it has been asserted, that the stagnation is due to a mechanical impediment, resulting from the contracted state of the lungs in such cases, this has been clearly proved not to be the fact, by causing animals to breathe a gas destitute of oxygen, so as to cause Asphyxia in a different manner; the same stagnation resulting as in the other case. The influence of the prolonged application of cold to a part, may be quoted in support of the same general proposition; for, although the calibre of the vessels may be diminished by this agent, yet their contraction is not sufficient to account for the complete cessation of the flow of blood through them, which is well known to terminate in the loss of their vitality.

509. Many of the facts which indicate the influence of the capillaries on the amount and rapidity of the circulation through them, have been already adverted to. It is a general fact, unquestioned by any physiologists, that, when there is any local excitement to the processes of nutrition, secretion, &c., a determination of blood towards the part speedily takes place, and the motion of blood through it is increased in rapidity; and although it might be urged that this increased determination may not be the effect, but the cause, of the increased local action, such an opinion could not be sustained without many inconsistencies with known facts. For it is known that such local determination may take place, not only as a part of the regular phenomena of growth and development (as in the case of the entire genital system at the time of puberty and of periodical heat, the uterus after conception, and the mammæ after parturition), but also as a consequence of a strictly-local cause. Thus the student is well aware that, after several hours' close application, there is commonly an increased determination of blood to the brain, causing a sense of oppression, a feeling of heat, and frequently a diminished action in other parts; and, again, when the capillary circulation is being examined under the microscope, it is seen to be quickened by moderate stimuli, and equally retarded by depressing agents. All these facts harmonize completely with the phenomena which are yet more striking in the lower classes of organized beings, and are evidently the results of the same laws.

510. If the phenomena which have been here brought together be considered as establishing the existence, in all classes of beings possessing a circulating apparatus, of a capillary power, which affords a necessary condition for the movement of the nutritious fluid, through those parts in which it comes into more immediate relation with the solids,—the question still remains open, as to its nature. That the capillaries possess a contractile power, in a far higher degree than do the large arteries, and more easily excited than that of the smaller, appears scarcely to admit of doubt; though to what it is due, may be reasonably questioned. It has been recently asserted by Schwann, that they possess the same kind of fibrous tissue in their walls as do the large vessels: and this cannot be regarded as improbable. It is not possible, however, that their contractility could have any influence in aiding the continuous motion of blood through them, unless it were exercised in a very different manner from that of which observation affords us evidence. For, when we are microscopically examining the

capillary circulation of any part, it is at once seen that the vessels present no obvious movement, and that the stream, now rendered continuous by the elasticity of the arteries, passes through them as through unelastic tubes. The only method in which the contractility of the capillaries could produce a regular influence on the current of blood, would be an alternate contraction and dilatation, or a peristaltic movement; and of neither of these can the least traces be discerned. Hence we should altogether dismiss from our minds the idea of any *mechanical* assistance afforded by the action of the capillaries to the movement of the blood. That the contractile coat of the capillaries has for its office to regulate the calibre of the vessels, can scarcely be doubted; but any general permanent contraction would only occasion an obstacle to the circulation,—as is shown by the effects of stimulating injections, which, if thrown into the vessels before their vitality has been lost, will not pass through the capillaries. It would appear, therefore, to be through their action on this coat, that local stimuli occasion a contraction of the capillaries; their effect, however, is different from what might have been anticipated; for, instead of the capillary circulation being retarded, it is accelerated, at least until an abnormal condition results from their continued operation. Here, again, is another evidence, that something different from mechanical power must be the agent that operates in all the foregoing cases.

511. The nature of this agent is at present very obscure; and it may not be in our power for some time to unveil it. The conditions of its action, however, lie open for investigation; and it appears from the foregoing facts that a very simple and constant expression of these may be given.—Whilst the injection of blood into the capillary vessels of every part of the system is due to the action of the heart, its rate of passage through those vessels is greatly modified by the degree of activity in the processes to which it should normally be subservient in them,—the current being rendered more rapid by an increase in their activity, and being stagnated by their depression or total cessation. This is little else than a modification of the ancient aphorism,—*ubi stimulus, ibi fluxus*. Thus it seems that "the capillaries possess a *distributive* power over the blood, regulating the local circulation, independently of the central organ, in obedience to the necessities of each part."* If this be true, it is evident that the dilatation or contraction of the capillaries will only have a secondary influence on the movement of the blood through them. The former condition is usually an indication of diminished vital energy; and when it is observed, it is almost invariably accompanied by a retardation or partial stagnation of the current; on the other hand, the application of a moderate stimulus, which excites the contractility, accelerates for a time the motion of the blood, by rendering more energetic that reaction between the fluids and the surrounding tissues, which is the condition that really has the most influence over the current. It is not enough to object to such a doctrine, that we know nothing of the mode in which this reaction affects the movement of the blood; since we are equally ignorant of the *modus operandi* of many other causes whose real existence is fully acknowledged,—as for instance the effect of a stimulus applied to a motor nerve, in causing contraction of the muscle supplied by it.

512. An attempt has been made by Dr. Alison, to give more precision to the foregoing statement, by attributing the effect to a series of "vital attractions and repulsions," created by the operations to which the blood in the capillaries is subservient; he considers that the particles of blood are

* See Palmer's Edition of Hunter, Vol. III. p. 232. Note by Mr. P.

drawn towards the solids surrounding the capillaries, so long as they have not come into close relation with them; but that, after accomplishing the purposes of their circulation, they are again repelled by the same property. It is very possible that these attractions and repulsions may have a real existence, and may be the operative causes in producing the phenomena in question, without being essentially different in character from those which are witnessed in Physics and Chemistry; it seems desirable, therefore, not to apply to them the term vital, which denotes, if it mean any thing, that they are to be referred to a set of laws entirely different. That alterations in the chemical state of the blood (involving, of course, important changes in its vital properties) are capable of exercising a most important effect on the capillary circulation, is shown, not merely by the phenomena of Asphyxia already referred to, but by the curious fact recently ascertained by Dr. J. Reid,—that the blood, when imperfectly arterialized, is retarded in the systemic capillaries, causing an increased pressure on the walls of the arteries. He found that, when the ingress of air through the trachea of a dog was prevented, and the asphyxia was proceeding to the stage of insensibility,—the attempts at inspiration being few and laboured, and the blood in an exposed artery being quite venous in its character,—the pressure upon the arterial walls, as indicated by the hæmadynamometer applied to the femoral artery, was much greater than usual. Upon applying a similar test to a vein, however, it was found that the pressure was proportionably diminished; whence it became apparent that there was an unusual obstruction to the passage of venous blood through the systemic capillaries. After this period, however, the mercury in the hæmadynamometer applied to the artery began to fall steadily, and at last rapidly, in consequence of the diminished force of the heart, and the retardation of the blood in the pulmonic capillaries; but, if atmospheric air was admitted, the mercury rose very speedily, showing that the renewal of the proper chemical state of the blood restored the condition necessary for its circulation through the capillaries.

513. It can be scarcely doubted, that it is by some influence exercised over the molecular actions to which the blood is subject in the capillaries, that the nervous system can operate on the functions of nutrition, secretion, &c., in the manner already alluded to; and this influence may be not improperly termed vital, if by so designating it we merely imply that its nature and mode of operation are unknown, but that it is closely connected with those actions which are altogether peculiar to living beings. The following experiment, made by Dr. Wilson Philip, exhibits in a convincing manner the possibility of such an influence. "The web of one of the hind legs of a frog was brought before the microscope; and while Dr. Hastings observed the circulation, which was vigorous, the brain was crushed by the blow of a hammer. The vessels of the web *instantly* lost their power, the circulation ceasing; an effect which cannot arise, as we have seen, from the ceasing of the action of the heart. [Dr. P. here refers to experiments by which it was ascertained, that the circulation in the capillary vessels of the frog will continue for several minutes after the interruption of the heart's action.] In a short time the blood again began to move, but with less force. This experiment was repeated, with the same result. If the brain is not completely crushed, although the animal is killed, the blow, instead of destroying the circulation, increases its rapidity."* We are not hence to conclude, however, that the nervous system supplies any influence, which is essential

* Experimental Inquiry into the Laws of the Vital Functions, 4th edition, p. 52.

to the continuance of the circulation; since it is only by such sudden and severe injuries to the nervous centres as instantaneously destroy the vitality of the whole system (§ 380) that the movement of the blood is arrested. The experiments of Müller and others satisfactorily prove, that mere action of the nerves does not produce any direct effect upon the capillary circulation; and this corresponds with the well-known fact that the nutritive processes may continue as usual after this action has been suspended. All the facts which bear upon the question, of the connection between nervous agency and the capillary circulation, have an equal relation to the functions of nutrition and secretion in general.

Of the Venous Circulation.

514. The Venous system takes its origin in the small trunks that are formed by the re-union of the capillaries; and it returns the blood from these to the heart. The structure of the veins is essentially the same with that of the arteries; but whilst their middle coat possesses considerable elasticity, it appears less endowed with any peculiar vital property.* The elasticity of the veins is shown by the jet of blood which at first spouts out in ordinary venesection, when, by means of the ligature, a distention has been occasioned in the tubes below it. A slight contractility on the application of stimuli has been observed; but this is not so decided as in the arteries. The whole capacity of the venous system is considerably greater than that of the arterial; the former is usually estimated to contain from two to three times as much blood as the latter, in the ordinary condition of the circulation; and when we consider the great proportion which the veins in almost every part of the body bear to the arteries, we shall scarcely regard even the larger of these ratios as exaggerated. Of course the rapidity of the movement of the blood in the two systems will bear an inverse ratio to their respective capacities; thus if, in a given length, the veins contain three times as much blood as the arteries, the fluid will move with only one-third of the velocity. Even at their origins in the capillary plexus, the veins are larger than are the arteries which terminate in the same plexus; so that, wherever the arterial and venous networks form distinct strata, they are readily distinguished from each other. The veins are remarkable for the number of valves which they contain, formed of duplicatures or loose folds of the internal tunic, between the component laminæ of which contractile fibres are interposed; and for the dilatations behind these, which, when distended, give them a varicose appearance. The valves are single in the small veins, the free edge of the flap closing against the opposite of the vein; in the larger trunks they are double, and in a few instances are composed of three flaps. The object of these valves is evidently to prevent the reflux of blood; and we shall presently see that they are of important use in assisting in the maintenance of the venous circulation. They are most numerous in the veins which run among parts affected by muscular movement; they are not found in the veins of the lungs, of the abdominal viscera, or of the brain.

515. The movement of the blood through the veins is without doubt chiefly effected by the *vis a tergo* or propulsive force which results from the action of the heart and from that of the arteries and capillary vessels.

* It is stated, however, by Gerber (General Anatomy, p. 296) that the fibres of the middle coat of the veins bear a stronger resemblance to those of muscular tissue, than do those of the corresponding part of the arteries, which more resemble the ordinary elastic fibres. It is not improbable that his observations were made on portions of the veins near the heart, which partake of its contractility (§ 483).

This is shown by the immediate arrestment of it which takes place when these forces are suspended. There are some concurrent causes, however, which are supposed by some to have much influence upon it, and of which the consideration must not be neglected. One of these is the suction power attributed to the heart, acting as a *vis a fronte* in drawing the blood towards it. It is very doubtful how far the auricles have such a power of active dilatation, as that which would be required for this purpose; and no sufficient evidence has been given that the current of blood at any distance from the heart is affected by it. Indeed, for a reason to be presently given, this may be regarded as impossible. Another important agency has been found by some physiologists in the inspiratory movement; this is supposed to draw the blood of the veins into the chest, in order to supply the vacuum which is created there at the moment of the descent of the diaphragm. That the movement in question has *some* influence on the flow of venous blood into the chest, is evident from the occurrence of the *respiratory pulse* long ago described by Haller, which may be seen in the veins of the neck and shoulder in thin persons, and in those especially who are suffering from pulmonary diseases: during expiration, the veins are seen to be partially emptied; whilst during inspiration they become turgid, partly in consequence of the accumulation from behind and of the check in front, and partly (it may be) in some cases through an absolute reflux from the veins within the chest (§ 489). It was maintained by Sir D. Barry, that the suction of the blood towards the chest in inspiration is one of the most important causes of the maintenance of the venous circulation; but several considerations agree in pointing to the conclusion, that no great influence can be rightly attributed to it. The pulmonary circulation, being entirely within the chest, cannot be affected by variations in atmospheric pressure; and it may be further remarked, that the whole mechanism of respiration is so different in Birds, from that which exists in Mammalia, that no vacuum can ever be said to exist in *their* chests, although the venous circulation is performed as actively as usual. The venous circulation of the fœtus, also, is independent of any such agency. Again, it has been shown experimentally by Dr. Arnott and others, that no suction power exerted at the further end of a long tube, whose walls are as deficient in firmness as are those of the veins, can occasion any acceleration in a current of fluid transmitted through it; for the effect of the suction is destroyed, at no great distance from the point at which it is applied, by the flapping together of the sides of the vessel. There can be no question about the fact, however, that in the immediate neighbourhood of the chest, the flow of blood towards the heart is aided by inspiration and impeded by expiration; for Sir D. Barry's experiment,—which consisted in introducing one extremity of a tube into the jugular vein of a horse, and the other into water, which exhibited an alternate elevation and depression with inspiration and expiration,—has been repeated and confirmed by several physiologists. It is evident that the suction of blood into the chest will aid the flow through the veins, by removing the obstacle to it in front, although it does not exercise any more direct influence over the current at a distance. On the other hand, the expiratory movement, while it directly causes accumulation in the veins, will assist the heart in propelling the blood into the arteries; and the combined action of these two causes produces, among other effects, the rising and sinking of the brain, synchronously with expiration and inspiration, which are observed when a portion of the cranium is removed.

516. It has been suggested by Prof. Dunglison,* that the return of

* Physiology, Vol. II. p. 180.

blood to the heart may be attributed to the simple law of hydrostatic pressure, which causes fluids everywhere to seek their own level; since, in all the arteries which proceed downward from the arch of the aorta, the force of gravity will act in such a manner as of itself to raise the blood to an equivalent height in the veins. But this doctrine appears liable to two serious objections. When the body is in a recumbent posture, the greater part of the vascular system is very nearly upon the same level. Moreover, the influence of the force in question would scarcely be felt through the plexus of capillary vessels; for, the interposition of a system of tubes even of much larger calibre would be, by the friction created between the fluid and their walls, an effectual obstacle to the rapid ascent of a current, which had so slight an impetus as that derived from its previous fall. That gravity has an influence in modifying the circulation in particular parts, however, is a fact well known, especially in certain diseased states; and the keeping an inflamed part at as high a level as possible, is often one of the most important therapeutic means that can be adopted. One of the most powerful of the general causes which influence the venous circulation, is doubtless the frequently-recurring action of the muscles upon their trunks. In every instance that muscular movement takes place, a portion of the veins of the part will undergo compression; and as the blood is prevented, by the valves in the veins, from being driven back into the small vessels, it is necessarily forced on towards the heart. As each set of muscles is relaxed, the veins compressed by it fill out again,—to be again compressed by the renewal of the force. That the general muscular movement is an important agent in maintaining the circulation at a point above that at which it would be kept by the action of the heart and capillaries alone, appears from several considerations. The pulsations are diminished in frequency by rest, accelerated by exertion, and very much quickened by violent effort. In all kinds of exercise, and in almost every sort of effort, there is that alternate contraction and relaxation of particular groups of muscles, which has been just mentioned as affecting the flow of blood through the veins; and there can be little doubt that the increased rapidity of the return of blood through them, is of itself a sufficient cause for the accelerated movements of the heart. When a large number of muscles are put in action after repose, as is the case when we rise up from a recumbent or a sitting posture, the blood is driven to the heart with a very strong impetus; and if that organ should be diseased, it may arrive there in a larger quantity than can be disposed of, and sudden death may be the result. Hence the necessity for the avoidance of all sudden and violent movements, on the part of those who labour under either a functional or structural disease of the centre of the circulation.

Peculiarities of the Circulation in different parts.

517. In several portions of the Human body, there are certain varieties in the distribution, and in the functional actions, of the blood-vessels, which should not be omitted in a general account of the Circulation. Of these, we have in the first place to notice the apparatus for the pulmonary circulation; the chief peculiarity of which is, that *venous* blood is sent *from* the heart, through a tube which is arterial in its structure, and that *arterial* blood is returned *to* the heart, through a vessel whose entire character is that of a vein. The movement of the blood through these is considerably affected by the physical state of the lungs themselves; being retarded by any causes which can occasion pressure on the vessels (such as over-disten-

tion of the cells with air, obstruction of their cavity by solid or fluid depositions, or by foreign substances injected into them, &c.), and proceeding with the greatest energy and regularity when the respiratory movements are freely performed. The portal circulation, again, is peculiar in being a kind of offset from the general or systemic circulation; for the vena porta, although it originates in the capillary plexus of the intestines, acquires, by the time it has arrived at the liver, the character of an artery, being then an afferent or distributive vessel, and subdividing into a capillary plexus from which veins are to originate. This is very much the character of the aorta of Fishes, which does not arise directly from the heart, but is formed by the reunion of the branchial veins, which have collected the aerated blood from the gills. The whole portal system is destitute of valves; and it may be surmised with much probability, that the purpose of their absence is to allow of an unusually free passage of blood from one part of that system to another, during the very varying conditions to which it is subjected (§ 709).

518. Another very important modification of the circulating system is that which presents itself within the cranium. From the circumstance of the cranium being a closed cavity, which must be always filled with the same total amount of contents, the flow of blood through its vessels is attended with some peculiarities. The pressure of the atmosphere is here exerted rather to keep the blood in the head, than to force it out; and it might accordingly be inferred that, whilst the quantity of cerebral matter remains the same, the amount of blood in the cranial vessels must also be invariable. This inference appears to derive support from the experiments of Dr. Kellie.* On bleeding animals to death, he found that, whilst the remainder of the body was completely exsanguine, the usual quantity of blood remained in the arteries and veins of the cranium; but that, if an opening was made in the skull, the vessels were then as completely emptied as the rest. It is not to be hence inferred, however, that the absolute quantity of blood within the cranium is not subject to variation, and that in the states of inflammation, congestion, or other morbid affections, there is only a disturbance of the usual balance of the arterial and venous circulation. The fact in all probability is rather, that the softness of the cerebral tissue, and its varying functional activity, render it peculiarly liable to undergo alterations in bulk; and that the quantity of blood may thus, even in the healthy condition, be continually changing. Moreover, in disordered states of the circulation, the quantity of blood in the vessels of the cranium may be for a time diminished by sudden extravasation, either of blood or serum, into the cerebral substance; and the amount of interior *pressure* upon the walls of the vessels may also be considerably altered, even when there is no difference in the *quantity* of fluid contained in them.

519. The erectile tissues constitute another curious modification of the ordinary vascular apparatus. The chief of these are the corpora cavernosa in the penis of the male, and the clitoris of the female, the collection of similar tissue round the vagina and in the nymphæ of the female, and the nipple in both sexes. In all these situations, erection takes place as a result of certain emotional conditions of the mind, the influence of which is probably transmitted through the sympathetic nerve, as it may be experienced even in cases of paraplegia. The erectile tissue appears essentially to consist of a plexus of varicose veins, enclosed in a fibrous envelope. According to Gerber,† this plexus is traversed by numerous contractile

* Edinburgh Medico-Chirurgical Transactions, Vol. I.
† Op. cit. p. 298.

fibres, which are analogous to those that form the dartos; and to the contraction of these is probably to be attributed the obstruction to the return of blood by the veins, which is the occasion of the turgescence. The proximate cause of the erection of the penis has been stated by some to be the action of the ischio-cavernosi muscles; and by others it has been attributed to the compression of the vena dorsalis penis against the symphysis pubis. But it is obvious that nothing analogous to this can apply to the other erectile organs, especially to the nipple. In the penis, according to the discovery of Müller, there are two sets of arteries; of which one, destined for the nutrition of the tissues, communicates with the veins in the usual way, through a capillary network; whilst the others pass off as large branches, and penetrate the cavernous substance in a helicine manner, communicating abruptly with the venous cells. It would seem not improbable, that these last do not ordinarily convey blood; but that the same change in the contractile fibres, which impedes the return of the blood by the veins, may also permit it to enter more freely from the helicine arteries. It has been maintained by some, that the iris is rather an erectile than a muscular organ; and as the fibres which can be traced in it resemble those of erectile tissues, it is not improbable that their office may be rather to regulate the injection of this organ with blood, than to change its condition in any other manner.

CHAPTER X.

ON RESPIRATION.

520. It is obvious that the nutritive fluid, in its circulation through the capillaries of the system, must undergo great alterations, both in its physical constitution, and in its vital properties. It gives up to the tissues with which it is brought into contact, some of its most important elements; and, at the same time, it is made the vehicle of the removal, from these tissues, of ingredients which are no longer in the state of combination that fits them for their offices in the animal economy. To separate these ingredients from the general current of the circulation, and to carry them out of the system, is the great object of the Excretory organs; and it is very evident that the importance of the respective functions of these, will vary with the amount of the ingredient which they have to separate, and with the deleterious influence which its retention would exert on the welfare of the system at large. Of all these injurious ingredients, carbonic acid is without doubt the most abundantly introduced into the nutritive fluid; and it is also most deleterious in its effects on the system if allowed to accumulate. One of the most important changes which results from its retention, is the stagnation of the blood, both in the systemic and pulmonary capillaries; for there is evidence that, if the process of aeration, by which the venous blood brought to the lungs is converted into arterial, be in any way checked, the flow of blood through the pulmonary capillaries speedily ceases; and that if venous blood be propelled through the system, in place of arterial, it is transmitted with difficulty through the systemic vessels. The cause is the same in both instances;—the normal changes which the blood ought to undergo in these vessels are prevented; and there is consequently a cessation of that capil-

lary power, which has been shown to be one of the most important of the forces by which the blood is kept in motion (§ 511).

521. We find, accordingly, that the provision for the removal of carbon from the blood, surpasses in extent that which is made for any other excretion. The two largest glands in the body—the Liver and the Lungs—are designed for this purpose; but their operation is made subservient, in each case, to other objects. By the Liver, the carbon is excreted, with other elements, in the form of a fluid which has important uses in the digestive function; whilst by the Lungs (which will be presently seen to have in all essential points a glandular structure) it is thrown off in a gaseous form, and thus is made subservient, according to the laws of the mutual diffusion of gases, to the introduction of oxygen into the system, and consequently to the maintenance of the animal temperature, as well as of the stimulating properties of the blood. It is evident, then, that any circumstances which check the excretion of carbonic acid by the lungs, will have an immediately injurious effect upon the system at large; by causing the accumulation, in the fluid upon which it is dependent for the performance of its vital actions, of an agent that so seriously injures its vivifying properties. But this is not the only mode in which the cessation of this function becomes injurious. The exclusion of a constant supply of oxygen from the blood, even though the removal of the carbonic acid were provided for by other means, deprives it of its due power of nourishing and exciting to action the tissues and organs to which it is afterwards distributed; for it would appear that this element is, throughout animated nature, a stimulant as essential to the energy of its operations, as caloric is to all, and light to many of these. Further, in those animals in which (as in Man) the whole current of blood passes through the respiratory apparatus, any stagnation in its capillaries must derange, and soon check, the systemic circulation. There are some animals, however, (such as Reptiles,) in which only a portion of the blood that has returned from the system is transmitted to the lungs by each impulse of the heart; so that their pulmonary circulation is in some respects upon the footing of the portal circulation in other animals: in such, therefore, the interruption of the pulmonary circulation will not immediately suspend the movement of the blood through the systemic vessels; and in the Batrachia, whose soft, moist skin, allows the air to act with tolerable freedom upon the blood contained in its vessels, life may be prolonged for a considerable time, even after the complete removal of the lungs, provided the temperature be low.* But if, under these circumstances, the skin be covered with any unctuous substance, preventing the transmission of air, death speedily ensues.

522. The necessity for the aeration of the circulating fluid, is most remarkably exemplified in the provision which is made for it in every living being; such provision being more universally found than that for any other function, except for the ingestion of aliment, and for the perpetuation of the race. Even in Plants, a true respiration is continually going on, although its effects are sometimes obscured by those of a converse change, which is subservient to a different purpose. It has been ascertained that the absorption of oxygen and the extrication of carbonic acid never cease during the life of the plant,—taking place under all conditions, by day and by night, in sunshine and in shade. This is their true Respiration. But Plants obtain from the atmosphere a large proportion of the carbon which they require as food; and this they procure by decomposing the carbonic acid of the air,

* See Edwards on the Influence of Physical Agents on Life (Translation by Hodgkin), p. 32.

absorbing or fixing its carbon, and setting free its oxygen. Now to this process, which is only performed by the green parts of plants, and under the influence of light, the name Digestion has not improperly been given. A healthy Plant will fix in this manner much more carbon than it sets free by Respiration; so that its effect upon the atmosphere is, on the whole, to aid in purifying it from the deleterious ingredient so largely imparted to it by Animal Respiration, combustion, &c. The Fungi, however, derive their support, like Animals, only from matter which has been previously organized: and *their* respiration is uncompensated by the fixation of carbon from the atmosphere. The same is the case during the processes of flowering and germination in the higher Plants; for certain chemical conversions are then taking place, which involve the liberation of a large amount of carbonic acid, and a corresponding absorption of oxygen, without any counterbalancing change.* In no Plants is there any distinct respiratory circulation; since the nutritious fluid can be brought into close relation with the air in almost every part of its course. There is, however, a rudiment of an internal respiratory apparatus, in a system of air-vessels, or *tracheæ*, composed of membranous tubes kept pervious by an elastic spiral fibre which winds within them, and closely resembling the air-tubes of Insects.

523. In the Animal kingdom we almost universally find distinct organs for the aeration of the blood; these are always formed upon the same general plan, being essentially composed of a membranous prolongation of the external surface, adapted by its vascularity and permeability to bring the blood into close relation with the surrounding medium. But as this medium may be either air or water, we find two principal forms of the apparatus, one of them adapted for each kind of respiration. In aquatic animals, the membrane is usually prolonged externally into tufts or fringes, which are so arranged as to expose the greatest amount of surface to the water; each filament of which these are composed includes an afferent and efferent capillary vessel; and it is whilst the fluid is passing through them, that its aeration is accomplished. The collection of tufts or fringes constitutes what are known as *gills;* and though their arrangement varies considerably, their essential character is but little different, throughout the classes of animals that possess them. On the other hand, in air-breathing Animals, the aerating surface is reflected inwardly, forming passages or chambers, into which the air is received, and on the walls of which the blood is distributed in a minute capillary network. Such a conformation is found even among some of the lower Articulata, which have a series of air-sacs disposed along each side of the body, one for every segment. In Insects we find, instead of these sacs, a system of prolonged tubes, ramifying through the body, and carrying air into its minutest portions. Even in some Mollusca, such as the Snail and other terrestrial Gasteropods, we find a provision for aerial respiration; a large cavity being formed in the back, communicating with the air, and having a beautifully-reticulated plexus of blood-vessels on its walls. In none of the Invertebrata, however, does the respiratory apparatus communicate with the mouth, which is an organ solely appropriated in them to the ingestion of food. In the Mollusca, indeed, the channel through which the water that has passed over the aerating surface, is expelled from the chamber (formed by a fold of the mantle or general envelope) that contains the gills, is the same as that through which the excrementitious matter is discharged from the intestine; and the gills themselves are very commonly situated in the neighbour-

* See Principles of General and Comparative Physiology, § 440 et seq.

hood of the anal orifice. This fact is interesting in regard to the character of the temporary respiratory apparatus of the Human embryo. In Fishes and the larvæ of Batrachia, which are the highest animals that breathe by gills, these organs are so disposed in connection with the cavity of the mouth, that fresh currents of water are continually being forced over them by its muscles; and thus the energy of their action is greatly increased. Moreover, the whole blood which is propelled from the heart, proceeds first to the respiratory organs, instead of passing through them on its return from the systemic circulation, as in most of the aquatic Invertebrata. Still, as the quantity of oxygen which the blood can obtain in this manner is very small, being limited to that contained in the atmospheric air dissolved in the water, the amount of aeration must be considered as low.

524. In the lowest Vertebrata that possess any thing like a pulmonary cavity, this has a structure as simple as that of the air-sac of the Snail. This is the case in many Fishes, where it is known as the air-bladder; it is frequently single in this class, and communicates with the intestinal canal near the stomach, or is altogether destitute of outlet. In others, however, it is double, and its duct opens into the œsophagus near the mouth; so that its analogy to the lungs of higher animals is very evident. The Batrachia begin life as Fishes, breathing by gills during their tadpole state; but at the time that the legs are developed and the tail has decreased, the pulmonary organs also are evolved, and the course of the blood is altered, so that it is no longer transmitted through the gills, which speedily shrivel and disappear (§ 42). There are some species, however, whose metamorphosis is checked, so that in their permanent condition both lungs and gills are present; but the former are then present in a very rudimentary form, not being more developed than the air-sacs of many Fishes. The lungs of Reptiles are, almost universally, simple sacs with little subdivision into cells. Where such subdivision exists, it is usually at the upper part of each lung, the rest being one undivided bag, on the walls of which the pulmonary vessels are distributed. They afford us, therefore, a good opportunity of studying the distribution of these vessels; and the accompanying figures represent the course of the circulation as observed in them. It will be seen that the trunk of the pulmonary artery runs along one side of the sac, and that of the pulmonary vein along the other; and that numerous branches arise from the former, which subdivide into capillaries that ramify over the whole surface, and then reunite into small veins which terminate in the latter. The islets of parenchyma left between the capillary vessels are seen to be much smaller than those which are usually to be observed in the systemic circulation; so that the membrane is more copiously traversed by vessels than any other that is known. The walls of the capillaries, moreover, are much less distinct than those of the systemic circulation. These two conditions are obviously favourable to the exposure of the largest possible quantity of blood to the influence of the air; but as the surface is not an extensive one, the amount which can be thus exposed at any one time is very limited; and the pulmonary artery is in fact one of the smaller branches of the aorta, which conveys a mixed fluid to the system at large.

525. In the warm-blooded Vertebrata, which have a complete double circulation,—namely, Birds and Mammalia, a much larger extent of surface is provided for the aeration of the blood, the whole current of which is transmitted to the lungs before circulating again through the system. This increase is provided in Birds, partly by the more minute subdivision of the lungs into cells, and partly by the addition of a number of large air-sacs, which are disposed in various parts of the body and even in the interior of

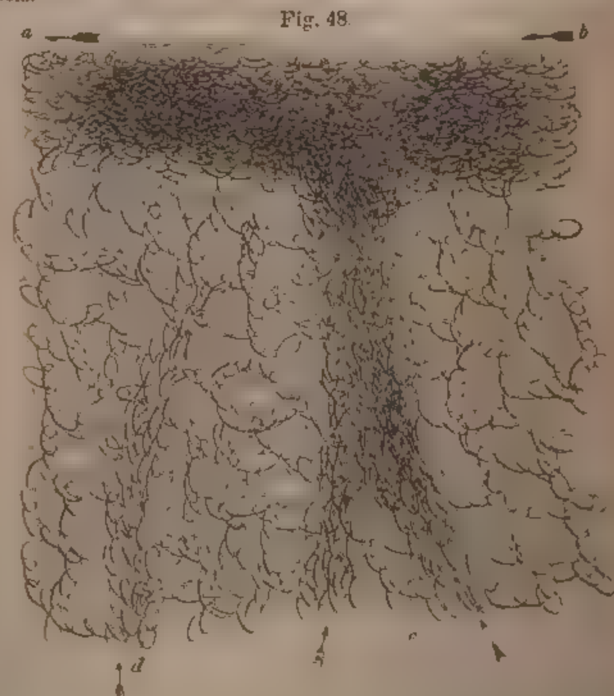
Fig. 46.

Lung of *Triton cristatus*, magnified about 3 diameters; *a*, pulmonary artery; *b*, pulmonary vein.

Fig. 47.

Portion of the lung of the same animal, more highly magnified; the vessels, finely injected with size and vermilion, form a network so intimate, that the parenchyma is only seen in small islets in its interstices. (After Wagner.)

Fig. 48.



Portion of the lung of a living *Triton*, as seen under the microscope with a power of 180 diam.; *a*, *b*, pulmonary vein, receiving blood from the large trunk *c*, and a smaller vessel, *d*. (After Wagner.)

the long bones. Hence it happens that the amount of Respiration is greater in this class than in any other, although the form of the apparatus is not nearly so concentrated as in the Mammalia, nor is the mechanism of the chest so well adapted to a constant exchange of the air contained in its cavities (§ 48). In Mammalia the lungs are proportionally smaller; and the whole respiratory apparatus is restricted to the thorax: but the minute subdivision of their cavity, and the mechanism by which a continual interchange of air is provided for, render them very efficient for their designed purpose. In regard to the intimate structure of the Lungs of Man and of the Mammalia, it is difficult to speak with confidence. It was maintained by Reissessen, and has been repeated by other anatomists, that the air-cells of the lungs are in reality the globular dilatations of the extremities of the ultimate ramifications of the bronchial tubes, analogous to the milk-cells of the Mammary gland (Fig. 73); but it has been objected, that they are much more numerous than these ramifications can be supposed to be; and there seems much reason to believe, that each tube leads to a cluster of cells, communicating with each other. If this be true, the analogy is still preserved between the structure of the Lungs, and that of the Glands, commonly so called; for we shall hereafter see that in the Liver, Kidneys, and probably in the Testis, the ducts seldom end in free extremities, but anastomose into a plexus.

526. The lungs are developed, in the first instance, as diverticula from the œsophageal tube. In the chick, about the fourth day, a little sacculus is described as shooting forth at its posterior and inferior part; and this soon subdivides at its lower part into two; at the same time becoming more separated from the tube, by a constriction around the neck, which soon elongates so as to form the trachea. On the fifth or sixth day, the lung of one side is completely distinct from that of the other, and each is attached to the common pedicle by a peculiar branch, the future bronchus. The upper portion has much thicker walls than the lower, and these appear to contain a large quantity of vesicular parenchyma, in which the ramifications of the bronchial tubes subsequently extend themselves. About the tenth or eleventh day of incubation, these ramifications possess nearly their permanent character and situation.

Fig. 49.

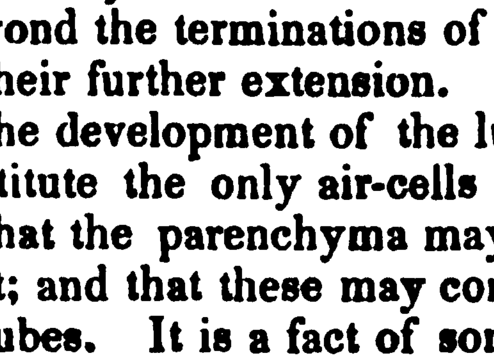
First appearance of the lungs; *a*, in a *Fowl* at four days; *b*, in a *Fowl* at six days; *c*, termination of bronchus in very young *Pig*. (After Rathkè.)

The first trace of the glottis appears about the fifth day; it is then a mere slit in the walls of the œsophagus, resembling that by which the ductus pneumaticus of some Fishes opens into the alimentary canal. The formation of the cartilaginous rings of the trachea does not commence until after the twelfth day, when they first appear as transverse striæ on the median line of the front only; they gradually become solid, and extend themselves on either side, until they nearly meet at last on the median line on the back or vertebral side of the tube. The history of the process in the Human embryo, appears to be very nearly the same. The first appearance of the lungs takes place about the sixth week, at which time they are simple vesicular prolongations of the œsophageal membrane. Their surface, however, soon becomes studded with numerous little wart-like projections; and these are caused by the formation of corresponding enlargements of their cavity. These enlargements soon become prolonged, and develope corresponding bud-like

enlargements from their sides; and in this manner the form of the organs is gradually changed, a progressive increase in their bulk taking place from above downwards, in consequence of the extension of the bronchial ramifications from the single tube at the apex. At the same time, however, a corresponding increase in the amount of the parenchymatous tissue of the lung is taking place; for this is deposited in all the interstices between the bronchial ramifications, and might be compared with the soil filling up the spaces amongst the roots of a tree. It is in this parenchyma that the pulmonary vessels are distributed; and in the portion of it which extends beyond the terminations of the bronchial tubes seems to act as the nidus for their further extension. It can be easily shown that, up to a late period of the development of the lungs, the dilated terminations of the bronchi constitute the only air-cells (Fig. 49, *c*): but it would not seem improbable, that the parenchyma may gradually have additional cavities formed within it; and that these may communicate with each other and with the bronchial tubes. It is a fact of some interest, as an example of the tendency of certain diseased conditions to produce a return to forms which are natural to the fœtal organism, or which present themselves in other animals,—that up to a late period in the development of the Human embryo, the lungs do not nearly fill the cavity of the chest, and the pleura of each side contains a good deal of serous fluid.

527. Whatever be the view entertained of the minute structure of the Lungs, there is no difference of opinion as to the main physiological fact, that these organs consist of a congeries of minute air-cells, whose cavities are capable of dilatation and contraction, and on whose walls a very minute plexus of capillary blood-vessels is distributed. This network is described by Reissessen as so minute, that the diameter of the meshes is scarcely so great as that of the capillary vessels which form it. The diameter of the pulmonary vesicles is about twenty times greater than that of the capillaries which are distributed upon its parieties, varying (according to the measurement of Weber) from the $\frac{1}{199}$th to $_{1}$th of an inch. There is no evidence that the alteration in the size of the air-cells which takes place during the respiratory process, is due to any other cause than the simple elasticity of their walls; but the bronchial tubes certainly possess a considerable amount of contractility, which can scarcely be regarded as otherwise than muscular. From the experiments of Dr. C. B. Williams* it appears that all the air-tubes are endowed with a considerable amount of irritability, which may be excited by electrical, chemical, or mechanical stimuli, applied to themselves, but not readily (if at all) excitable through their nerves. This contractility resembles that of the intestines or arteries, more than that of the voluntary muscles or heart; the contraction and relaxation being more gradual than that of the latter; though less tardy than that of the former. It is chiefly manifested in the smaller bronchial tubes; since in the trachea and the larger bronchi, the cartilaginous rings prevent any decided diminution in the calibre of the tube. Wedemeyer did not succeed in producing any distinct contraction of the fibres of the trachea and larger bronchi; but he states that tubes of less than a line in

Fig 50.



Portion of the lung of a *Pig*, the terminal vesicles being filled with mercury; A, natural size, B, moderately magnified. (After Wagner.)

* Athenæum Report of the Meeting of the British Association, 1840, p. 802.

diameter could be perceived to contract gradually under the stimulus of galvanism, until their cavity was nearly obliterated. It is remarked by Dr. Williams, that the irritability of the bronchial muscles is soon exhausted by the action of a stimulus; but that it may in some degree be restored by rest, even when the lung is removed from the body. When the stimulation is long continued, however, as by intense irritation of the mucous membrane during life, the contractile tissue passes into a state which resembles that of the tonic contraction of muscular fibre (§ 390). The contractility is greatly affected by the mode of death, and is remarkably diminished by the action of vegetable narcotics, particularly stramonium and belladonna; whilst it seems to be scarcely at all affected by hydrocyanic acid. These facts are very important as throwing light upon certain diseased conditions. It has long been suspected that the dyspnœa of Spasmodic Asthma depends upon a constricted state of the smaller bronchial tubes, excited through the nervous system, frequently by a stimulating cause at some distance; and there can now be little doubt that this is the case. That they should not be readily excited to contraction by a galvanic stimulus applied to their nerves, is no valid argument against this view; as it was long held that the muscular coat of the alimentary canal also was completely removed from nervous influence, which is now well known to be not by any means the case. The peculiar influence of stramonium and belladonna, in diminishing the contractility of these fibres, harmonizes remarkably with the well known fact of the relief frequently afforded by them in this distressing malady.

528. Notwithstanding the high degree of contractility which the bronchial tubes have been shown to possess, there is no valid reason for the belief that they contribute by any rhythmical movement to the exchange of the contained air, which, in the healthy state, is continually taking place. For it can be scarcely imagined that they should, by any power of their own, contract and dilate uniformly with the contraction and expansion of the chest, unless their muscles were equally subject with those of the thorax, to the influence of the nervous system. The lungs themselves, then, are to be regarded as quite passive in the movements of respiration; the renewal of their contained air being accomplished by the action of the muscles external to the thorax, or partly forming its parietes. The lung completely fills the cavity of the pleura, in the healthy state at least; so that, when this is enlarged, a vacuum is produced, which can only be filled by a corresponding enlargement of the lung; and to produce this, the air rushes down the trachea and passes to the remotest air-cells. The distension of the whole tissue of the lung, which is affected in this manner, is much more complete than that which could be occasioned by simple insufflation from the trachea;—a fact of which it has been proposed to take advantage in juridical inquiries in regard to suspected cases of Infanticide, where the lungs are found to float, and the defence is set up that the child was stillborn, and that air was blown into the chest for the purpose of resuscitating it. It has been ascertained by the experiments of Mr. Jennings,* that if a piece of lung, which has been filled with air by insufflation, be exposed to great pressure, the air may be expelled from it sufficiently to cause it to sink in water; but that no pressure can produce the same effect upon that which has been filled by a natural inspiratory effort. It is a serious objection to the use of this test in juridical investigations, however, that the early inspiratory efforts of the infant are often so feeble, as to produce but a very imperfect dilatation of the air-cells; so that the lung of an infant which has

* Transactions of the Provincial, Medical and Surgical Association, Vol. II.

naturally inspired cannot, by such means, be distinguished from one that has been artificially inflated. The fact ascertained by Mr. J., however, is one of much physiological interest. Owing to the freedom with which the air enters the lungs, when there is no abnormal obstruction, the external surface is always in contact with the walls of the chest, so that the pulmonary and costal pleuræ glide over one another with every inspiration and expiration. The smooth and moistened character of their surface prevents the movement from producing any sound; but it becomes evident when the friction is increased, either by the dryness that is commonly one of the early changes produced by inflammation, or by the rough deposit that subsequently appears.

529. The complete dependence of the expansion of the lungs upon the production of a vacuum in the chest, is well shown by the effect of admission of air into the pleural cavity. When an aperture is made on either side, so that the air rushes in at each inspiratory movement, the expansion of the lung on that side is diminished, or entirely prevented, in proportion to the size of the aperture. If air can enter through it more readily than through the trachea, an entire collapse of the lung takes place; and by making such an aperture on each side, complete asphyxia is produced. But if it be too small to admit the very ready passage of air, the vacuum produced by the inspiratory movement is more easily filled by the distension of the lungs, than by the rush of air into the pleural cavity; so that a sufficient amount of change takes place for the maintenance of life. This is frequently observed in the case of penetrating wounds of the thorax, in the surgical treatment of which, it is of great importance to close the aperture as completely as possible; when this has been accomplished, the air that had found its way into the cavity is soon absorbed, and the lung resumes its full play. Where one lung is obstructed by tubercular deposit, or is prevented in any other way from rightly discharging its function, an opening that freely admits air into the pleural cavity of the other side, is necessarily attended with an immediately fatal result; and in this manner it not unfrequently happens that chronic pulmonary diseases suddenly terminate in Asphyxia, a communication being opened by ulceration between a bronchial tube and the cavity of the thorax.

530. The dilatation of the chest during inspiration, is chiefly accomplished by the contraction of the diaphragm, which, from the high arch that it previously formed, becomes nearly plane; in this change of figure, it presses on the abdominal viscera, so as to cause them to protrude, which they are enabled to do by the relaxation of the abdominal muscles. In ordinary tranquil breathing, the action of the diaphragm is alone nearly sufficient to produce the necessary exchange of air; but, when a full inspiration is required, the cavity of the chest is dilated laterally, as well as inferiorly. This is accomplished by the intercostal muscles, the scaleni, serrati, and others, which, by elevating the ribs, bring them and their cartilages more nearly into the same direction, and thus separate them more widely from the median line. Expiration is chiefly effected by the contraction of the abdominal muscles, which at the same time force up the diaphragm by their pressure on the viscera, and depress the ribs; in the latter movement they are aided by the longissimus dorsi, sacrolumbalis, &c., and also by the elasticity of the cartilages of the ribs, with that of the air-cells and air-tubes themselves. It is difficult to form an estimate, by observations on one's self, of the usual number and degree of the respiratory movements; since the direction of the attention to them is certain to increase their frequency and amount. In general it may be stated, that from 14 to 18 alternations usually

occur in a minute; of these, the ordinary inspirations involve but little movement of the thorax; but a greater exertion is made at about every fifth recurrence. The average numerical proportion of the respiratory movements to the pulsations of the heart is about 1 to 5 or 4½; and when this proportion is widely departed from, there is reason to suspect some obstruction to the aeration of the blood, or some disorder of the nervous system. Thus in pneumonia, in which a greater or less proportion of the lung is unfit for its office, the number of respirations increases in a more rapid proportion than the acceleration of the pulse; so that the ratio becomes as one to three, or even one to two, in accordance with the degree of engorgement.* In hysterical patients, however, a similar increase, or even a greater one, may take place without any serious cause; thus Dr. Elliotson† mentions a case in which the respiratory movements of a young female, through nervous affection, were 98 or even 106, whilst the pulse was 104. On the other hand, the respirations in certain typhoid conditions, and in narcotic poisoning become abnormally slow, owing to the torpid condition of the nervous centres, the proportion being 1 to 6, or even 1 to 8; and in such cases, the lungs not unfrequently become œdematous, from the cause formerly mentioned (§§ 231 and 232).

531. The amount, also, of the respiratory movements is affected by various morbid conditions; thus when dislocation of the spine takes place above the origin of the intercostal nerves, but below that of the phrenic, so that the former are paralyzed, the respiratory movement is confined to the diaphragm, and as this is insufficient, serum is effused into the lungs, and a slow Asphyxia supervenes, which usually proves fatal in from three to seven days. Even where the muscles and nerves are all capable of action, the full performance of the inspiratory movements is prevented by the solidification or engorgement of any part of the lung, which interferes with its free distension, or by adhesions between the pleural surfaces, which offer a still more direct impediment. When these adhesions are of long standing, they are commonly stretched into bands, by the continual tension to which they are subjected. If the impeding cause affect both sides, the movements of both will be alike interfered with; but if one side only is affected, its movements will be diminished, whilst those of the other remain natural; and the physician hence frequently derives an indication of great value, in regard to the degree in which the lung is incapable of performing its functions. It is to be remembered, however, that the action both of the diaphragm and of the elevators of the ribs may be prevented, by pain either in the muscles themselves or in the parts which they move; thus the descent of the diaphragm is checked by inflammation of the abdominal viscera or of the peritoneum; and that of the intercostals by rheumatism, pleuritis, pericarditis, or other painful disorders of the parts forming the parietes of the thorax.

532. In regard to the capacity of the lungs, the quantity of air introduced and expelled at each ordinary respiratory movement, and the amount that remains after expiration, great discrepancy exists in the statements of the various experimenters who have endeavoured to ascertain them. This discrepancy has doubtless arisen in part from the circumstance already mentioned,—that *attention* to the respiratory movements will render them fuller and more frequent; and in part, also, from the degree of effort that is required to draw air from any kind of apparatus adapted to afford a mea-

* See a Paper by Dr. Hooker, on the Relation between the Respiratory and Circulating Functions, in the Boston (N. E.) Medical and Surgical Journal; an abstract of which will be found in the British and Foreign Medical Review, vol. vi. p. 263.

† Physiology, p. 215, note.

surement of the quantity inhaled, which effort will of itself cause the distension of the chest to be much greater than natural. The experiments of Messrs. Allen and Pepys seemed to give 16½ cubic inches as the average quantity taken in at each inspiration; whilst those of Menzies (who is followed by Dr. Bostock) caused him to rate it at 40 cubic inches. The most recent experiments on the subject are those of Mr. Coathupe,* in which the Author has much reason to feel confidence. According to his estimate, about 266⅓ cubic feet, or 460,224 cubic inches of air pass through the lungs in 24 hours; reckoning the average number of inspirations at 16 per minute, this would give 20 cubic inches as the amount inhaled at each. According to the experiments of Allen and Pepys, the quantity of air remaining in the lungs of a stout full-grown man after death, is about 100 cubic inches; this is probably less than the amount that remains after ordinary expiration.

Chemical Phenomena of Respiration.

533. We naturally pass from the foregoing inquiries, to those that relate to the alterations in the air, which are effected by Respiration. It was formerly supposed that the blood arrived at the lungs charged with carbon, —that this carbon was united in their cells to the oxygen of the atmosphere, —and that in this manner a certain amount of the oxygen of the inspired air was being continually converted into carbonic acid, which thus replaced it in the expired air. Subsequent researches, however, appear to have satisfactorily proved, that this is not a true account of the changes which take place in the lungs; and that it would be more correct to say, that the blood comes to the lungs charged with carbonic acid, which it imparts to the inspired air, at the same time abstracting from it a volume of oxygen which is always as large, and usually greater. Hence it is not correct to speak of a certain quantity of the inspired oxygen as being converted into carbonic acid in the lungs; but it should rather be said that a certain quantity of oxygen is absorbed, and a certain quantity (generally less than the equivalent bulk) of carbonic acid exhaled. The proportion of these quantities is by no means constant; varying with different species, and with the same animal at different ages, and at different periods of the year. According to Dr. Edwards, the quantity of oxygen which entirely disappears from the air is sometimes as much as one-third of the whole; it is greatest in the young animal, and is sometimes almost imperceptible in the adult.

534. The quantity of carbonic acid excreted has been estimated by some experimenters at as much as 39,600 cubic inches in twenty-four hours; this amount of gas would contain 5,148 grains, or 11 ounces (Troy) of solid carbon. Now that is more than is contained in six pounds of most kinds of solid food which man employs; for this usually contains three parts in four of water; and of the other fourth seldom more than one half is carbon. Hence, making no allowance for the quantity which passes off in other ways, more carbon is excreted from the lungs, upon this estimate, than is introduced in the usual daily quantum of food. It must, therefore, be erroneous. This estimate was formed upon the results of an experiment continued during a short time, in which, from the nature of the apparatus employed, the respirations were to a certain degree laborious, and the quantity of air renewed at each movement was therefore greater. In Mr. Coathupe's experiments, great care was taken to render the inspiration as

* Athenæum Report of Meeting of the British Association, 1839; p. 707.

free as possible from effort; and the measuring process was continued for a much longer time. According to his statement, the quantity of carbonic acid generated in twenty-four hours is above 17,856 cubic inches; this will contain 2,616 grains, or 5½ ounces of solid carbon,—a quantity which we may very well imagine to be thus excreted. The proportion of carbonic acid contained in the expired air appears from this estimate to be about 4 per cent., on the whole; but single experiments give a much higher estimate. Thus, in one of those made by Allen and Pepys, in which fresh air was taken in at every inspiration, the proportion was eight parts in every hundred. They found, however, that if the air be already charged in some degree with carbonic acid, the quantity excreted is much less; for when 300 cubic inches were respired for three minutes, only 28½ cubic inches of carbonic acid were found in it, although the rate of its production in a parallel experiment was 32 cubic inches a minute. Knowing, then, the necessity of a free excretion of carbonic acid, we are led by this fact to perceive the high importance of ventilation; for it is not sufficient for health, that a room should contain the quantity of air requisite for the support of its inhabitants during a given time; since after they have remained in it but a part of that time, the quantity of carbonic acid which its atmosphere will contain, will be large enough to interfere greatly with the due aeration of their blood, and thus to cause oppression of the brain and the other morbid affections that result from the accumulation of carbonic acid in the circulating fluid.

535. Although the statements just given may be regarded as representing the average amount of carbonic acid evolved during the twenty-four hours, the amount is subject to great variation under particular circumstances. Thus, during a state of muscular activity it is greatly increased. Mr. Newport has noticed that in Insects the difference is enormous,—their respiration being as feeble as that of cold-blooded animals when they are at rest, and more energetic (the quantity of oxygen consumed in proportion to their size being greater) than that of any other animals, when they are in active movement. In Man the difference is not so great, and its exact amount cannot be readily estimated; but it is unquestionable that an increase does take place. It has been ascertained by Dr. Prout, however, that, if the exercise be prolonged so as to occasion fatigue, a diminished consumption of oxygen takes place; he also states that the exhilarating passions increase, whilst the depressing passions (as also the use of alcohol and tea) diminish the quantity of carbonic acid exhaled. There is little doubt that there is a great diminution, also, during sleep; this may be partly due to the total cessation of muscular exertion, and partly to the greater retention of the heat which is the consequence of it. For it appears that the amount of carbonic acid produced is greatly influenced by the temperature; in the Guinea-pig, according to Crawford, the quantity exhaled at 104° is only half that which is generated at 55°. The final cause or purpose of this connection will be evident when we consider the subject of Animal Heat.

536. It has been supposed, until recently, that the azote of the air undergoes no change through Respiration; but the experiments of Dr. Edwards have shown that, although its quantity may remain nearly the same, there is a continual absorption and a continual exhalation of the gas. If the absorption be the more active, there will be a disappearance of azote from the air; if exhalation predominate, the proportion of this gas will be increased. Even in the same animal, there may be a variation in this respect at different periods of the year, and even at different parts of the day. Thus in nearly

all the lower animals on which he experimented, there was an augmentation in the quantity of azote during the summer, sometimes equalling in the course of the day the whole bulk of the animal. On the other hand, towards the end of October, he found that a diminution of the nitrogen began to be apparent; and this continued until the following spring.

537. The reaction which takes place between the air and the blood is easily explained upon physical principles. If the blood come to the lungs charged with carbonic acid, and is exposed in their cells to the influence of atmospheric air, which is a mixture of oxygen and nitrogen, an endosmose and exosmose of gases will take place, according to certain fixed laws.* The carbonic acid of the blood will pass out, to be replaced by oxygen and nitrogen; and the quantity of the former which enters will be much greater than that of the latter, on account of the superior facility with which oxygen passes through porous membranes. If the venous blood also contain nitrogen as well as carbonic acid, this also will pass out, to be replaced by the oxygen of the air. Thus, there will be a continual exosmose of carbonic acid and nitrogen, and a continual endosmose of oxygen and nitrogen; and the relative quantities of these gases exhaled and absorbed will be subject to continual variation from secondary causes.

Effects of Respiration on the Blood.

538. That an important change is effected in the character of the blood, by exposure to atmospheric air in the lungs, has been known, from the time when it was first ascertained that it is regularly transmitted to those organs. The most obvious part of this change is the alteration in its colour, from the dark purple of the venous fluid, to the rich crimson of the arterial. But this alteration is only the index of changes far more important, which occur in its chemical constitution. Respecting the nature of these changes, there has been, as formerly stated, much difference of opinion; some maintaining that the carbonic acid exhaled is formed in the lungs; and others, that it is contained in the venous blood, and is truly excreted from it. The latter opinion, which was long since brought forwards by La Grange and Hassenfratz, has recently obtained such full confirmation, from the experiments of Spallanzani, Edwards, Müller, Bischoff, Magnus, and others, that it will here be adopted as a physiological truth. These experiments are of two kinds; first, those which show that an exhalation of carbonic acid may continue for a long time, when the animal is breathing an atmosphere in which no oxygen exists; and, secondly, those which prove that much more carbonic acid exists in an uncombined state in venous blood than in arterial, whilst more oxygen exists in a similar condition in arterial blood than in venous. The results of these will now be briefly stated.

539. It was stated, long since, by Spallanzani, that Snails might be kept for a long period in hydrogen, without apparent injury to them; and that during this period they disengaged a considerable amount of carbonic acid. Dr. Edwards subsequently ascertained that, when Frogs were kept in hydrogen for several hours, the quantity of carbonic acid exhaled was fully as great as it would have been in atmospheric air, or even greater; this latter fact, if correct, may be accounted for, by the superior displacing power, which (on the laws of the diffusion of gases) hydrogen possesses for carbonic acid. Collard de Martigny repeated this experiment in nitrogen,

* See Principles of General and Comparative Physiology, § 437—9.

with the same results. In both sets of experiments, the precaution was used of compressing the flanks of the animal, previously to immersing it in the gas, so as to expel from the lungs whatever mixture of oxygen they might contain. These experiments have been since repeated by Müller and Bergemann, who took the additional precaution of removing, by means of the air-pump, all the atmospheric air that the lungs of the frog might previously contain, together with the carbonic acid that might exist in the alimentary canal. They found in one of their experiments, that the quantity of carbonic acid exhaled in hydrogen was nearly a cubic inch in 6½ hours; and in another, that nearly the same amount was given off in nitrogen, but this required rather a longer period. It appears from the table of their results,* that the amount was not ordinarily greater in the experiments which were prolonged for twelve or fourteen hours, than in those which were terminated in half the time; hence it may be inferred, that the quantity which the blood is itself capable of disengaging is limited, and that the absorption of oxygen is necessary to enable carbon to be set free from the tissues. An exception may be taken to all these experiments, on the ground that they were made upon cold-blooded animals; and that in the warm-blooded tribes the character of the change may be different. It is scarcely probable, however, that the uniformity of Nature should be thus violated. There is no difference in *kind* between the alterations effected in the air by the respiration of warm-blooded, and by that of cold-blooded animals; the only variation is in *degree*. Nor is there any appreciable difference in the character of the changes effected upon their venous blood, by the action of oxygen or of other gases. It is impossible, however, for an adult Bird or Mammal to sustain life for any considerable time in an atmosphere deprived of oxygen; since the greatly-increased rapidity and energy of all their vital operations, necessitates a much more constant supply of this vivifying agent, than is needed by the inferior tribes; and, as we shall presently see, the capillary action necessary for the passage of the blood through the lungs will not take place without it. But Dr. Edwards has shown that young Mammalia can sustain life in an atmosphere of hydrogen or nitrogen, for a sufficient length of time to exhale a sensible amount of carbonic acid; so that the character of the process is clearly proved to be the same in them as in Reptiles and Invertebrata.

540. That the change which venous blood undergoes in the lungs is to be explained upon principles of a purely chemical and physical nature, is evident from the fact, that the same changes will take place when it is exposed to the air out of the body, even through the medium of a thick membrane, such as a bladder. Such changes, however, only affect the surface of the fluid; but this is exactly what we should expect, since the air has no access to the part beneath. The blood whilst circulating through the capillaries of the lungs, is divided into an innumerable multitude of minute streamlets, each so small as to admit but a single layer of its corpuscles; and in these, therefore, the surface which is placed in contact with the air is so enormously extended, as to be almost beyond calculation. Hence, then, we can at once understand how a change may be instantaneously effected in it, which would occupy several hours, when the blood is less advantageously exposed to the influence of oxygen. The ultimate comparative analysis of venous and arterial blood indicates the predominance of carbon in the former, and of oxygen in the latter; and it would appear from

* Müller's Physiology, p. 338.

the experiments of Michaelis, that it is in the composition of the red particles, that the principal difference exists.*

Venous Blood.

	Carbon.	Nitrogen.	Hydrogen.	Oxygen.
Albumen	52·650	15·505	7·359	24·486
Cruor	53·231	17·392	7·711	21·666
Fibrin	50·440	17.267	8·228	24·065
Total in 300 parts .	156·321	50·164	23·298	70·217

Arterial Blood.

	Carbon.	Nitrogen.	Hydrogen.	Oxygen.
Albumen . . .	53·009	15·562	6·993	24·436
Cruor	51·382	17·253	8·354	23·011
Fibrin	51.374	17·587	7·254	23·785
Total in 300 parts	155·765	50·402	22·601	71·232

The analysis of Marcet gives a more decided predominance of carbon in venous blood and of oxygen in arterial; according to him, venous blood contains 55·7 per cent. of carbon, and only 21·7 per cent. of oxygen; whilst arterial blood contains only 50·2 per cent. of carbon, but as much as 26·3 per cent. of oxygen. The discrepancy between these results is probably to be accounted for by the fact to be presently noticed, regarding the facility with which important changes are effected in the gaseous contents of the blood, by a short exposure of it to the atmosphere. The analysis of Dr. Marcet probably over-states the difference between arterial and venous blood, as that of Michaelis underrates it; but from these and other data, the general fact of the predominance of oxygen in the former and of carbon in the latter may be confidently stated. Here, then, we have an important confirmation of the doctrine, that there is an absolute removal of oxygen from the air, during the process of respiration; and not a mere conversion of this gas into carbonic acid.

541. In what precise form the variable amount of these elements is contained in the blood, has not yet been clearly shown. That they must be partly combined with its other ingredients, and not merely dissolved in the fluid, is clear, from the changes which they produce in its aspect and properties. On the other hand, it appears indubitable that they partly exist in it in a mere state of solution, as carbonic acid and oxygen exist in ordinary water that has been exposed to the atmosphere. This may be regarded as established by the numerous experiments of Scudamore, Clanny, Bischoff, and others; which have shown that a small quantity of these gases may be removed from fresh-drawn blood, by exposing it to a vacuum. But the amount thus obtained is small in proportion to that, which may be procured by treating it with hydrogen or nitrogen; for these gases possess, according to the laws of mutual diffusion already referred to, a much greater power of displacing the carbonic acid and oxygen diffused through the blood, than is exerted by a vacuum. Carbonic acid, however, may be obtained from venous blood in considerable amount, by agitating it with atmospheric air, the oxygen and nitrogen of which have a powerful displacing influence upon

* Müller's Physiology, p. 323.

it; and it is probable that a large quantity is thus removed, during the flow of blood from the vein in ordinary bleeding, especially when the fluid does not spout forth in a full stream, but trickles down the arm in a shallow current. Hence in all experiments upon the gaseous contents of the blood, it is essential that it should flow direct from the orifice into the gas which is to operate upon it;* and to the neglect of this precaution may be traced much of the discrepancy that has prevailed among the several results which have been made public. The quantity of carbonic acid that may be obtained from venous blood by continued agitation of it with atmospheric air, is stated by Müller at half a cubic inch from seven cubic inches of the fluid; but when it is agitated with hydrogen, the quantity of carbonic acid obtained is sometimes as much as one-sixth of the volume of the blood. Hence we understand the mode, in which the respiration of hydrogen is a powerful cause of the extrication of carbonic acid from the lungs of those animals which can support life for some time without oxygen. The most important and satisfactory experiments that have been hitherto made upon the gases of the blood, are those of Magnus. He has shown that carbonic acid, oxygen, and nitrogen, may be extracted both from arterial and venous blood, but in varying proportion. The amount of oxygen in arterial blood equals at least one-third, and frequently almost one-half that of the carbonic acid; whilst in venous blood the oxygen is scarcely ever more than one-fourth, and often less than one-fifth, of the carbonic acid. The proportion of nitrogen seems to be continually varying, without any fixed law; it is sometimes as little as one-twelfth of the whole quantity of gas extracted from the blood; and sometimes nearly a fourth.

542. That the change of the colour of venous blood to that of arterial, is principally due to the replacement of its carbonic acid by oxygen, is very easily shown. The simple removal of the carbonic acid by hydrogen will not produce the alteration; it has been observed by Magnus, however, that a slight change of colour takes place in blood under the vacuum of an air-pump, although it does not nearly acquire the arterial tint. This falls in with what is known of the influence of carbonic acid on the blood: in common with other acids it has a blackening effect upon it, so that arterial blood when exposed to it becomes venous, and venous blood is rendered still darker; but the simple removal of it is not sufficient to restore the original hue. This restoration may be effected in two ways,—either by the addition of saline matter to the blood,—or by exposing the fluid to oxygen. The presence of a certain amount of saline matter appears, from the experiments of Dr. Stevens, to be a condition necessary for the due influence of oxygen upon the colouring matter of the blood; since if it be deficient, the contact of oxygen will not produce its usual effect. On the other hand, the addition of saline matter (especially nitre) will occasion a decided change of hue, without any extrication of carbonic acid or absorption of oxygen. Hence it appears that the presence of saline matter in the blood is an essential condition for the due effect of the process of oxygenation; and that the change of colour may be regarded as resulting from the conjoint operation of the removal of carbonic acid and the absorption of oxygen.

543. The aeration of the blood may take place, not only by means of the lungs, but also through the medium of the cutaneous surface. In some of the lower tribes of animals, indeed, this is a very important part of their respiratory process; and even in some Vertebrata, the cutaneous respiration

* An apparatus contrived for this purpose by Dr. Stevens, is described by him in the Phil. Trans. 1834.

is capable of supporting life for a considerable time. This is especially the case in the Batrachia, whose skin is soft, thin, and moist; and the effect is here the greater, since the blood which circulates through the system is, from the small proportion of it that has passed through the lungs, very imperfectly arterialized. By the experiments of Bischoff it was ascertained that, even after the lungs of a Frog had been removed, a quarter of a cubic inch of carbonic acid was exhaled from the skin, during eight hours. Experiments which have been made on the Human subject leave no room for doubt, that a similar process is effected through the medium of his general surface; for, when a limb has been enclosed for some hours in an air-tight vessel containing atmospheric air freed from carbonic acid, a sensible amount of this gas has been found to be generated. Moreover, it has been observed not unfrequently, that the livid tint of the skin which supervenes in Asphyxia, owing to the non-arterialization of the blood in the lungs, has given place after death to the fresh hue of health, owing to the reddening of the blood in the cutaneous capillaries by the action of the atmosphere upon them. (See also Chap. XIII.)

544. From the facts which have been stated, and from many others of the same kind, the conclusion seems indisputable, that the changes produced by Respiration are of the following nature. The arterial blood propelled from the heart to the system contains a large proportion of oxygen, either free or in loose combination with it; and also a certain amount of carbonic acid. During its passage through the systemic capillaries, it loses a part of its oxygen, and acquires a great increase in its amount of carbonic acid; and it returns to the heart in the state of venous blood, its colour having been darkened by the loss of its oxygen and by the influence of the acid. In the lungs, to which it is then transmitted, it undergoes by exposure to the atmosphere the converse change to that which took place in the systemic capillaries; a large part of its carbonic acid being removed, and a considerable addition being made to the amount of oxygen which it contains: its arterial hue and character are thus restored. It may be observed, then, that the blood, by its alternate passage through the systemic and pulmonary capillaries, serves to bring the two into close relation; and that in this manner, the oxygen of the air is enabled to act upon the minutest portions of those tissues of the body that are most distant from the lungs, as completely as it can do by being directly introduced into their substance, as it is in Insects. Owing to their constituting the portion of the blood most evidently affected by the processes of venalization and arterialization, the red corpuscles have been regarded by some as the principal vehicles for the oxygen and for the carbonic acid; but of this there is no sufficient evidence.

545. Much discussion has taken place upon the question, whether the exhalation of carbonic acid is to be regarded as a process of secretion; and it has been maintained by some (by Müller among the rest) that our power of explaining it on physical principles should prevent this view of it from being entertained. But it may be urged, on the other hand, that the Lungs have in all essential points a glandular structure, and that it is an ascertained fact, that the office of other glands, equally with theirs, is to separate from the blood ingredients which pre-exist in it; it can scarcely be regarded as improbable, therefore, that the process by which some of these elaborate their secretions is of a character equally physical with that by which the carbonic acid is thrown off from the lungs.

546. We have now to consider the results of the cessation of the Respiratory function, and the consequent retention of carbonic acid in the blood.

If this be sufficiently prolonged, a condition ensues to which the name of Asphyxia has been given; the essential character of which is the cessation of muscular movement, and shortly afterwards of the circulation; with an accumulation of blood in the venous system. The time which is necessary for life to be destroyed by asphyxia varies much, not only in different animals, but in different states of the same. Thus Warm-blooded animals are much sooner asphyxiated than Reptiles or Invertebrata; and, on the other hand, a hybernating Mammal supports life for many months with a respiration sufficiently low to produce speedy asphyxia if it were in a state of activity. And among Mammalia and Birds, there are many species which are adapted, by peculiarities of conformation, to sustain a deprivation of air for much more than the average period.* Excluding these, it may be stated as a general fact, that, if a warm-blooded animal in a state of activity be deprived of respiratory power, its muscular movements (with the exception of the contraction of the heart) will cease within five minutes, often within three; and that the circulation generally fails within ten minutes. Many persons, however, are capable of sustaining a deprivation of air for three, four, or even five minutes, without insensibility or any other injury; but this power, which seems possessed to the greatest degree by the divers of Ceylon, can only be acquired by habit. The period during which remedial means may be successful in restoring the activity of the vital and animal functions, is not, however, restricted to this. Cases are not unfrequent of the revival of drowned persons after a submersion of half an hour; and more than one has been credibly recorded, in which above three-quarters of an hour had elasped. It is not improbable, however, that in some of these cases a state of syncope had come on at the moment of immersion, through the influence of fear or other mental emotion, concussion of the brain, &c.; so that, when the circulation was thus enfeebled, the deprivation of air would not have the same injurious effect, as when this function was in full activity. The case would then closely resemble that of a hybernating animal; for in both instances the being might be said to live very slowly, and would therefore not require the usual amount of vital stimuli. The condition of the still-born infant is in some respects the same; and reanimation has been successfully attempted, when nearly half an hour had intervened between birth and the employment of resuscitating means, and when probably a much longer time had elapsed from the period of the suspension of the circulation.

547. It has now been sufficiently proved, both by experiment and by pathological observation, that the first effect of the non-arterialization of the blood in the lungs, is the retardation of the fluid in their capillaries; of which the accumulation in the venous system, and the deficient supply of the arterial, are the necessary consequences. It is some time, however, before a complete stagnation takes place from this cause; since, as long as the proportion of oxygen which remains in the air in the lungs is considerable, and that of the carbonic acid is small, so long will some imperfectly arterialized blood find its way back to the heart, and be transmitted to the system. This blood will have a depressing influence upon the functions of the brain and

* Thus, the Cetacea contain far more blood in their vessels, than do any other Mammalia; and these vessels are so arranged, that both arteries and veins are in connection with large reservoirs or diverticula. The reservoirs belonging to the former are usually full; but when the Whale remains long under water, the blood which they contain is gradually introduced into the circulation, and, after becoming venous, accumulates in the reservoirs connected with the venous system. By means of this provision, the Whale can remain under water for more than an hour.

of the muscular system, which influence is aided by the diminution that gradually takes place in the quantity of blood propelled through the aorta; and the actions of the respiratory muscles and of the heart will therefore soon become enfeebled. The cessation of the heart's contraction is due to two distinct causes, acting on the two sides; for on the right side it is the result of the over-distension of the walls of the ventricle, owing to the accumulation of venous blood; and on the left to the deficiency of the stimulus necessary to excite the movement. The property of contractility is not finally lost nearly as soon as the movements cease; for the action of the right ventricle may be renewed, for some time after it has ceased, by withdrawing a portion of its contents,—either through the pulmonary artery, their natural channel,—or, more directly, by an opening made in its own parietes, in the auricle, or in the jugular vein. (§ 489.) On the other hand, the left ventricle may be again set in action, by renewing its appropriate stimulus of arterial blood. Hence, if the stoppage of the circulation have not been of too long continuance, it may be renewed by artificial respiration; for the replacement by oxygen of the carbonic acid in the air-cells of the lungs, restores the circulation through the pulmonary capillaries, and thus at the same time relieves the distension of the right ventricle, and conveys to the left the due stimulus to its actions.

548. Of the mode in which the pulmonary circulation is stagnated by the want of oxygen, and renewed by its ingress into the lungs, no other explanation can be given, than that which has been heretofore offered of the capillary circulation in general,—namely, that the performance of the normal reaction between the blood and the surrounding medium (whether this be air, water, or solid organized tissue) is a condition necessary to the regular movement of the blood through the extreme vessels.* This view has recently obtained additional support from the experiments of Dr. J. Reid on the Respiration of Azote.† He found that, when the ordinary respiration of an animal is interrupted, and the Asphyxia is proceeding to the stage of insensibility, the first effect upon the arterial system is an increased distension (as indicated by the hæmadynamometer), even although the blood is at that time nearly venous in its character; this indicates that the fluid, now so perverted, is unable to pass with facility through the systemic capillaries, in consequence of its not being in a state fit for the performance of its normal actions. As the stagnation in the pulmonary capillaries becomes more complete, however, less and less blood is returned from the lungs to the heart; and, the systemic arteries being gradually unloaded without being refilled, the pressure of the blood upon their walls diminishes, and at last is no longer experienced. Its diminution is not arrested by causing the animal to breathe nitrogen, although the respiratory movements are renewed,—thus proving that the stagnation of the blood in the capillaries of the lungs is not due (as some have supposed) to a mechanical impediment; but the pressure is immediately increased by the admission of atmospheric air, which occasions the renewal of the pulmonary circulation, and the consequent increase in the supply of aerated blood to the systemic arteries.

Exhalation and Absorption by the Lungs.

549. The alteration in the porportions of its usual gaseous ingredients,

* For a fuller discussion of the Pathology of Asphyxia, see the Author's essay on the subject in the Library of Practical Medicine, Vol. III.

† Edinb. Med. and Surg. Journal, April, 1841.

is by no means the only change which the Blood undergoes in the Lungs. It parts, also, with a considerable amount of water, in the form of vapour; this usually contains a certain proportion of animal matter; and it is sometimes charged with volatile substances that have been elsewhere introduced into the blood, or which have been formed during its assimilation. It may also absorb from the atmosphere volatile matter diffused through it. Both these changes are probably to be explained upon simple physical principles; being dependent on the exposure of the blood to the atmosphere with a very extensive surface, and through a membrane of great permeability. Of the fluid ordinarily exhaled with the breath, a part doubtless proceeds from the moist lining of the nostrils, fauces, &c.; but it is indisputable that the greater proportion of it comes from the lungs; since, when the respiration is entirely performed through a canula introduced into the trachea, the proportion of watery vapour which the breath contains, is still very considerable. The quantity which thus passes off is by no means trifling; probably between 16 and 20 ounces in the twenty-four hours. It is not so liable to variation under the influence of temperature, the movement of the surrounding air, and other similar causes, as is the cutaneous transpiration; for air introduced into the air-cells of the lungs will, under almost all circumstances, be nearly the same in regard to such conditions, and will, therefore, dissolve an equal amount of watery vapour. It is considered by Dr. Prout, (and, in the Author's opinion, with much probability,) that the principal source of this vapour is not the blood properly so called, but the chyle and lymph which has just been introduced into it from the thoracic duct; a loss of a portion of their fluid being required to give them sufficient concentration. A process very analogous takes place in Plants; for a very large proportion of the water taken up in the crude sap is parted with in the leaves; and this concentration is one important step in the process, by which the crude sap is converted into the latex or nutritious juice. The fluid thrown off from the lungs is not pure water. It holds in solution, as might have been expected, a considerable amount of carbonic acid, and also some animal matter; the exact nature of the latter, which according to Collard de Martigny constitutes about 3 parts in 1000, has not been ascertained. If the fluid be kept in a closed vessel, and be exposed to an elevated temperature, a very evident putrid odour is exhaled by it. Every one knows that the breath itself has, occasionally in some persons, and constantly in others, a fetid taint; when this does not proceed from carious teeth, ulcerations in the air-passages, disease in the lungs, or other similar causes, it must result from the excretion of the odorous matter, in combination with watery vapour, from the pulmonary surface. That this is the true account of it seems evident, from the analogous phenomenon of the excretion of turpentine, camphor, alcohol, and other odorous substances, which have been introduced into the venous system, either by natural absorption, or by direct injection; and also from the suddenness with which it manifests itself, when the digestive apparatus is slightly disordered.

550. The Lungs are capable, under peculiar circumstances, of absorbing fluid from the atmosphere. Thus Dr. Madden* has shown that, if the vapour of hot water be inhaled for some time together, the loss by exhalation is found to be so much less than usual, as to indicate that the cutaneous transpiration is partly counterbalanced by pulmonary absorption, the pulmonary exhalation being at the same time entirely checked. It is probable that, if the quantity of fluid in the blood had been previously diminished by excessive

* Prize Essay on Cutaneous Absorption, p. 55.

sweating, or by other copious fluid secretions, the pulmonary absorption would have been much greater. Still in the cases formerly mentioned (§ 462), in which a large increase in weight could only be accounted for on the supposition of absorption of water from the atmosphere, it seems probable that the cutaneous surface was chiefly concerned; for it can only be when the air introduced into the lungs is saturated with watery vapour, that the usual exhalation will be checked, or that any absorption can take place. That absorption of volatile matter diffused through the air is, however, continually taking place by the lungs, is easily demonstrated. A familiar example is the effect of the inhalation of the vapour of turpentine upon the urinary excretion. It can only be in this manner that those gases act upon the system, which have a noxious or poisonous effect when mingled in small quantities in the atmosphere. Of these, sulphuretted hydrogen is one of the most powerful in its action; for it has been found that air impregnated with 1-1500th part of it will kill a bird in a very short time; and that a quantity but little more than double, namely 1-800th part, will soon kill a dog. This gas is exhaled in large quantities from many forms of decomposing animal and vegetable matter; and it has recently been shown (by Professor Daniell) to be absorbed by the water of the estuaries of those African rivers, whose mouths are regarded as among the most pestilential spots upon the surface of the globe. Carburetted hydrogen is another gas whose effects are similar; but a larger proportion is required to destroy life.

551. Carbonic acid gas, also, appears to be absorbed by the lungs, when a large proportion of it is contained in the atmosphere. The accumulation of this gas in the blood, when the respired air is charged with it even to a moderate amount, might be attributed to the impediments thus offered to its ordinary exhalation; but the following experiment appears to prove that it may be actually absorbed into the blood, and will thus exert a real poisonous influence, and not merely produce an asphyxiating effect. It was found by Rolando that the air-tube of one lung of the land-tortoise may be tied, without apparently doing any material injury to the animal, as the respiration performed by the other is sufficient to maintain life for some time; but, having contrived to make a tortoise inhale carbonic acid by one lung, whilst it breathed air by the other, he found that the animal died in a few hours.* Cyanogen is another gas which has an actively-poisonous influence upon animals, when absorbed into the lungs; its agency, also, is of a narcotic character. It is singular that the effects of the respiration of pure oxygen should not be dissimilar. At first, the rapidity of the pulse and the number of the respirations are increased, and the animal appears to suffer little or no inconvenience for an hour; but symptoms of coma then gradually develope themselves, and death ensues in six, ten, or twelve hours. If the animals are removed into the air before the insensibility is considerable, they then quickly recover. When the body is examined, the heart is seen beating strongly, while the diaphragm is motionless; the whole blood in the veins as well as in the arteries is of a bright scarlet colour; and several of the membranous surfaces have the same tint. The blood is observed to coagulate with remarkable rapidity; and it is to the alteration in its properties occasioned by the hyper-arterial-

* The fatal result of breathing the fumes of charcoal is, therefore, not simple asphyxia, such as would result from breathing hydrogen or nitrogen. Other volatile products are set free in the combustion of charcoal, besides carbonic acid. Mr. Coathupe (loc. cit.) states these to be Carbonate, Muriate, and Sulphate of Ammonia, carbonic oxide, oxygen, nitrogen, watery vapour, and empyreumatic oil; to these sulphurous acid may appear to be properly added.

ization, and indicated by this condition, that we are probably to attribute the fatal result. There can be no doubt that in this instance an undue amount of oxygen is absorbed. Death is also caused by the inhalation of several gases of an irritant character, such as sulphurous, nitrous, and muriatic acids; but it is doubtful how far they are absorbed, or how far their injurious effects are due to the abnormal action which they excite in the lining membrane of the air-cells and tubes. It cannot be doubted that miasmata and other morbific agents diffused through the atmosphere, are more readily introduced into the system through the pulmonary surface than by any other; and our aim should therefore be directed to the discovery of some counteracting agents which can be introduced in the same manner. The pulmonary surface affords a channel for the introduction of certain medicines that can be raised in vapour, when it is desired to affect the system with them speedily and powerfully; such are iodine, mercury, tobacco, stramonium, &c.

CHAPTER XI.

OF NUTRITION.

551. The Function of Nutrition essentially consists of the conversion of the fluid alimentary materials,—prepared by the Digestive process, and introduced into the system by Absorption,—into organized tissue, possessed of certain properties which inorganic matter never exhibits, and which, being neither physical nor chemical, are termed *Vital.* We shall hereafter see reason to believe that the manifestation of these vital properties, which gives rise to the various phenomena of Life, is to be considered as a result of the process of organization to which matter is subjected in the living body (§ 560).

Organizable Principles.

552. It has been shown (§ 464) that the Chyle taken up by the lacteals is composed of water holding albumen and saline matter in solution, and having oily matter mingled with it. Albumen may be regarded as the proximate element at the expense of which all the animal tissues are formed; and it seems to hold very much the same station in the Animal economy with Gum in the Vegetable. As long as this compound remains in the state which is regarded by Chemists as characteristic of it, it exhibits no trace of organization; and it is only when it has been brought under the influence of a living tissue, that it undergoes any important change in its characters. It is properly designated an *organizable* compound; and its composition appears to be such, that the Chemist need not despair of being ultimately able to produce it in his laboratory. The properties of albumen may be studied in the white of egg, or in the serum of blood, from both of which situations it may be obtained in a pure state by very simple means. In the animal fluids it exists in a soluble state; and even when it has been dried (at a temperature of 120°) it is readily dissolved again in water, forming a glairy, colourless, and nearly tasteless fluid. When dissolved in water, it coagu-

lates at 158°; a very dilute solution, however, does not become turbid until it is boiled. When the coagulation of Albumen takes place rapidly, a coherent mass is formed, which shows no trace whatever of organization; but, when the process is more gradual, minute granules present themselves, which do not, however, exhibit any tendency towards a higher form of structure. It is thrown down from its solution, in a coagulated state, by alcohol, creosote, and by most acids (particularly nitric) with the exception of the acetic. These precipitates are definite compounds of the acids with the albumen, which here acts the part of a base. On the other hand, coagulated albumen dissolves in caustic alkalies, and neutralizes them; so that it must here act as an acid. A solution of albumen in water is precipitated by acetate of lead and by many other metallic solutions; and insoluble compounds are formed, of which one—the albuminate of the chloride of mercury—is of much interest, as being that which is produced by the mixture of a solution of albumen with one of corrosive sublimate. Albumen, both in its soluble and insoluble state, always contains a certain amount of sulphur (§ 455), which blackens metallic silver. Soluble albumen dissolves phosphate of lime; and about two per cent. of this salt may be separated from it in its coagulated state.

553. Subsequently to its introduction into the living system, albumen undergoes a very peculiar modification, by which it is converted into Fibrin. As already mentioned (§ 464) it appears from the most exact analyses, that the ultimate composition of these two substances is the same; but their properties are widely different; and this may be regarded as an instance in which there is an analogy among Organic compounds, with the phenomena of *Isomerism* in Inorganic Chemistry. We shall presently see that Fibrin may be regarded as albumen in which the process of organization has begun; its molecules being ready to assume the peculiar arrangement that is so designated; but this arrangement only takes place completely, when the fibrinous mass is in contact with a living tissue, and is therefore to a certain degree under its influence. Fibrin, like albumen, may exist in a soluble or in a coagulated state; its soluble form only occurs, however, in the living animal fluids,—the chyle, lymph, and blood,—and it seems to be the intermediate condition between the soluble albumen, and the solid organized substances which are formed from it. When withdrawn from the blood-vessels, the blood soon coagulates (as do also the chyle and lymph, when they contain sufficient fibrin, §§ 564 and 565); and this coagulation is entirely due to a change in the condition of the fibrin, the particles of which have a tendency to aggregation. The fibrin may be obtained in a separate form by stirring fresh-drawn blood with a stick, to which it adheres in threads; these contain some fatty matter which is to be washed out with alcohol. In this condition it possesses the softness and elasticity which characterize the flesh of animals, and contains about three-fourths of its weight of water. It may be deprived of this water in dry air, and then becomes a hard and brittle substance; but, like flesh, it imbibes water again when moistened, and recovers its original softness and elasticity. When burned, it always leaves, like albumen, a portion of phosphate of lime. Fibrin is insoluble in alcohol and ether, and also, under ordinary circumstances, in water; but when long boiled in water, especially under pressure, its nature is altered, and it becomes soluble. This is also the case with coagulated albumen. Fibrin, like albumen, unites with acids as a base, forming definite compounds; and with bases as an acid. Its correspondence with albumen has been recently proved by the fact (first stated by M. Denis) that it may be entirely dissolved in a solution of nitrate of potash; and that this solution is coagulated

by heat, and greatly resembles a solution of albumen. This is only true, however, of the ordinary fibrin of venous blood; for that obtained from arterial blood, from the buffy coat, or from fibrin exposed for some time to the air, is not thus soluble. This is an important and interesting circumstance. The difference appears to depend upon the larger quantity of oxygen contained in the latter; for a solution of venous fibrin in nitre, contained in a deep cylindrical jar, allows a precipitate in fine flocks to fall gradually, provided the air have access to the surface, but not if it be prevented from coming in contact with the fluid; this precipitate is insoluble in the solution of nitre, and possesses the properties of arterial fibrin.* Hence it may be inferred that the fibrin of venous blood most nearly resembles albumen; whilst that of arterial blood, and of the buffy coat, contains more oxygen, and is more highly animalized. It is evident from this circumstance, that the matter of the red corpuscles is by no means the only constituent of the blood which undergoes a change in the respiratory process.

554. It is in the Fibrin of the Blood, which appears to be formed by the action of the living solids upon its Albumen (§ 566), that all the organized or structuralized constituents of the body have their immediate origin. Hence it has been designated as the general formative element, or *blastema*, (germinal matter). When withdrawn from the body and left to itself, it forms a firm coagulum, which has been designated as hyaline or vitreous substance, from its apparent homogeneousness; a similar substance constitutes a large proportion of certain animal solids. When decomposition commences in this mass (and even in the greatly-debilitated living body, in which the fibrin appears to be imperfectly formed,) a granular mode of aggregation is evident in the fibrinous coagulum.† According to Mr. Gulliver's recent observations, distinct traces of organization may not unfrequently be detected in the hyaline substance. When a clot has been hardened by boiling, and the thinnest edge of a thin slice is examined under the highest power of the microscope, a distinctly fibrillated arrangement may be generally seen. The fibrils sometimes unite into a delicate framework of areolar tissue; the interspaces of which are filled up with fibrinous pulp, either quite homogeneous, or pervaded by most minute molecules. In the midst of the coagulum certain other bodies often present themselves, which are probably to be considered as germs of the simplest forms of organized tissue. The nature of these will be better understood, after what is known of the first process of organization has been stated.

Formation of Cells.

555. A very large proportion of the Vegetable Organism (in the simplest Plants the entire structure) is made up of cells or vesicles, which are minute closed sacs, whose walls are composed in the first instance of a delicate membrane, frequently strengthened, at a period long subsequent to their first formation, by some internal deposit. The form of these cells is extremely variable, and depends chiefly upon the degree and direction of the pressure to which they may have been subjected at the period of their origin and subsequently to it. Sometimes they are spheroidal; sometimes

* Scherer, Chemisch-physiologische Untersuchungen; Annalen der Chemie, Oct. 1841; quoted in Graham's Chemistry, p. 1025.

† It has been shown by Mr. Gulliver, that the substance which is occasionally found in the interior of fibrinous clots, and which has been considered by Gendrin and other French pathologists as *pus*, is nothing else than softened fibrin. The granules are far more minute than the real pus-globules hereafter to be described.

cubical or prismatic; sometimes cylindrical; and sometimes very much prolonged. These cells may undergo various transformations. One of the most common is the conversion of several into a continuous tube. This is principally seen in the vessels through which the sap ascends the stem; these appear to have been formed by the breaking down of the transverse partitions between a regular series of cylindrical cells laid end to end; and the remains of such partitions may frequently be seen in them. The ducts which convey the ascending sap do not inosculate with each other, their purpose being merely to carry it direct to the leaves; but the vessels through which the descending or elaborated sap flows are of very different character; for their purpose is to distribute the nutritious fluid through the tissues (§ 497); and they anastomose very freely, just as do the capillaries of Animals. The network which they form, however, can be as clearly traced to an origin in cells whose cavities were originally distinct, as can the bundles of straight non-communicating ducts. Another important transformation of the original cells is that by which the woody fibres, that compose nearly all the fibrous textures of Vegetables, are produced. These fibres are still cells, but their form is very much elongated; they have a fusiform or spindle shape, being tubes drawn to a point at each end; at first they are quite pervious, like ordinary cells, but in the older wood their cavity is filled up by interior deposit. There seems reason to believe that fasciculi of these fibre-cells originate within certain of the ordinary cells of the primary cellular tissue; for in the young Plant, the latter alone can be detected; and it is not until the operation of the leaves has fairly commenced that any true woody structure is formed. Thus, *cells* or *vesicles* may be regarded as the *primordia* of all the Vegetable tissues. The next question is,—how are cells formed?

556. Cells may originate in two modes; either in an organizable fluid, under the influence of a living solid tissue with which it is in contact;—or in the interior of previously-formed cells. Both these modes may be observed in the Animal as well as in the Vegetable organism; and the right comprehension of them is of the utmost importance. It has been remarked that Gum holds the same rank in the economy of the Plant, as Albumen does in that of the Animal; and the glutinous compound which exists in the elaborated sap, and which is especially abundant in parts where organization is taking place with rapidity, may be compared with Fibrin. This glutinous sap undergoes a sort of coagulation when withdrawn from the vessels; and it may be sometimes perceived to resolve itself into distinct organic forms. The process of organization may be observed with the greatest facility in the embryonal sac, previously to fecundation. This contains, when first developed, a consistent gummy fluid, slightly wanting in transparency, but not exhibiting any granules; the addition of tincture of iodine produces a sort of granular coagulum, of a pale yellow. The first perceptible stage of organization is the appearance in this fluid of a number of extremely minute granules, which render it opalescent and almost opaque. The fluid then takes from iodine a somewhat darker tinge; and the granules, when their small size permits their colour to be distinguished, seem to become of a dark brownish yellow. Single, larger, and more sharply-defined granules are next evident in the mass; and these soon present a regular form, and increase in size, apparently from the coagulation of the minuter granules around the larger ones. These bodies usually assume a flattened disc-like form, with a circular or oval outline; and as they speedily become subservient to the formation of cells, they have been termed *cytoblasts* or cell-germs. From the surface of each of these, a

delicate transparent membrane is seen to project, as a watch-glass does from the dial; and this is the commencement of the cell. The membrane gradually projects more and more, and extends beyond the cytoblast, which is at last seen as a mere spot upon its walls. It is some time in acquiring consistence; for even after the cell has arrived at nearly its full size, it may be made to dissolve by agitation in the surrounding fluid. In fact, a disappearance not unfrequently takes place as a part of the natural course of vital phenomena; the cell-walls melting away before they have acquired consistence enough to be permanent. When the cell is complete, the granular cytoblast commonly disappears; sometimes, however, it remains in the wall of the cell, where (in the orders Orchideæ and Cacteæ) it has been long known under the name of the *nucleus*. By Schleiden, the original observer of these phenomena,* it is considered that the function of the cytoblast is complete with the formation of the primordial cell; but there is strong reason to believe, that the granules of which it is composed are the germs of new cells afterwards to be developed within the parent vesicle; and that, even when it disappears, it is by a resolution into its component granules, which may act as well separately as in apposition.

557. We are thus brought to the second mode in which cells may be developed, which is within the parent vesicles or primordial cells; the granules contained in these being apparently the germs from which they originate. This is probably the mode which is always followed when a tissue previously existing has to be extended or partially renewed; the former one being adopted where a structure entirely new has to be evolved, which is normally the case in certain phases of Vegetable life, but is less common in Animals. The secondary cells developed within a parent vesicle, originating in the granular germs which it includes, at first grow at the expense of the fluid it contains, and afterwards by absorbing nutrient materials through its walls. When they have undergone great increase in size, they distend the original vesicle, in such a manner that its limits are no longer apparent. The pressure to which they are subjected during their development determines their form, as in the previous case. If the original cell be spherical, and the pressure be equal on all sides, they also will be spherical until their sides are flattened against each other, when they will become rhomboidal dodecahedrons. If, on the other hand, the pressure be predominant in one direction, or there be any traction in another, the newly-forming cells will be elongated in the direction of least resistance; and this elongation may be carried to such an extent as to impart to them the fibrous character. The development of cells within cells is most distinctly seen in the case of the spore or pollen-grain; the granules contained in which are clearly the germs of the cells, that compose the tissue of the embryonic structure. These cells, when fully evolved, in their turn produce others in their interiors; and in this manner a complex and extensive organism may be developed from a single cell-germ. This, in fact, is what takes place in the lowest Plants, in which the cell-germs or reproductive granules are set free from the parent vesicle before they are themselves developed into cells; and each one of them, imbibing nutriment from the air and moisture around, may ultimately evolve itself into a complete individual. In the higher Cryptogamic Plants, on the contrary, the parent vesicle or spore does not rupture, but the new cells of the embryo are developed within it, at last distending its walls so much that they can be no

* See Müller's Archiv., 1838, p. 137, Taylor's Scientific Memoirs, Vol. II., and the Brit. and For. Med. Rev., Vol. IX. p. 499.

longer traced; and it would seem as if it served to elaborate for them, from the surrounding elements, the nutriment they require. In the Flowering-Plants, a further supply of this nutriment is provided in the ovule, where materials previously elaborated are stored up, to be absorbed through the wall of the parent cell, and to be subservient to the development of its contained germs. This process, although forming a part of the function of Reproduction, is in reality essentially the same with the ordinary nutritive operations; for in these the circulating fluid supplies the *pabulum* or organizable matter; whilst the cells already formed contain the germs, which, with the assistance of this, evolve themselves into new cells, and thus become the means of the extension of the original structure.

558. The animal body exhibits phenomena of a character essentially the same. Even in the fully-formed organism, many parts may be found, which are composed, more or less evidently, of isolated cells or vesicles, analogous to those of Plants; and it has been fully proved that, in its early condition, the whole fabric has this character. In fact, it has been shown by the researches of Barry, Schwann, and Valentin, that the whole structure originates in a single cell; that this cell gives birth to others analogous to itself, and these again to many future generations; and that all the varied tissues of the Animal body are developed from cells, between which no difference can be in the first instance observed. The multiplication of cells appears to take place upon the plan just stated, two or more being produced within the parent vesicle;—and this alike in the earliest condition of the embryo, and in the more advanced stages of the formation of its tissues. (See Plate I., Figs. 9—12, and Explanation.) The organizable fluid, then, prepared by the digestive process, is converted into organized tissue, by supplying the materials for this continual reproduction; the formation itself is dependent upon the powers of the solid texture.

559. This is not, however, the only mode in which new cells are produced in the Animal body; for they may originate in Fibrin, from nuclei or cytoblasts, which are formed by the aggregation of minute granules, just as do those of the Plant in the organizable gummy fluid of the ovule. Both require, for their perfect performance, that the fluid should be in contact with a living tissue; and, when this condition is applied, there seems to be no necessity for any further assistance; but traces of vesicular organization may often be discovered in fibrin, even after it has been drawn from the vessels of the living body, though more frequently, perhaps, in that which has coagulated within the vessels after death.* The vesicles, where they present themselves, possess nuclei, and have all the characters of newly-forming cells; and frequently the nuclei can be distinguished when no cells yet appear. It is, however, when fibrin is effused, in the form of coagulable lymph on a cut surface, or on an inflamed membrane, that this process of organization most unequivocally displays itself. Soon after the coagulation, a number of granular bodies may be seen in the mass; and these soon present appearances which indicate that they serve as nuclei for the formation of cells. By that time, the masses of granules have acquired such a consistence, that they may be peeled off in cohering shreds from the membranes to which they are attached; and they present a ruddy yellow colour, which corresponds with that of the chyle-globules. The exudation-cells are laid flat over one another, forming many superimposed layers, which unite into membranous expansions, that bear a strong resemblance to the layers of flat cells of which epithelium is composed;

* See Mr. Gulliver's Appendix to Gerber's General Anatomy, p. 31.

their margins are at first rounded, and they are united by a connecting medium, which gradually disappears, leaving the sides coherent to each other, so that the figure of the disk is changed into a polygon. These cells are afterwards metamorphosed into the various forms of tissue that are to present themselves in the new fabric, by a series of changes which will be hereafter more fully described. The process appears to be identical, whether the tissue be developed from the exudation-corpuscles which originate in the fibrin itself, or whether it be formed from cells previously existing. In both cases, the apparently homogeneous mass of vesicles is converted into a structure of a very heterogeneous description; some of the cells being converted into muscular fibre, others into nerve-tubes, others into bone, and so on. By what circumstances these differences are produced, either in the embryo, or in the newly-developed parts of the adult body, it is not easy to imagine. The cells all *appear* to be similar; yet development of every one must proceed in a determinate direction, or no regularity in the fabric could be the result.

560. From what has been stated, it appears evident that the process of Nutrition consists in the growth of the individual cells composing the fabric; and that these derive their support from the organic compounds with which they are supplied by the blood, just as the cells composing the simplest Plants derive theirs from the inorganic elements which surround them; and as different species of the latter select and combine these, in such modes and proportions as to give rise to organisms of very diversified forms and properties, so is it easily intelligible that the different parts of the fabric of the highest Animals should exercise a similar selective power, in regard to the materials with which the blood supplies them. The structure composing every separate portion of the body has what may be termed a *special affinity* for some particular constituents of the blood; causing it to abstract from that fluid, and to convert into its own substance, certain of its elements. This conversion is termed *Assimilation*. The property by which the cells of the Animal or Vegetable structure are enabled to perform it, is one of which we are not likely ever to know more. It will probably long remain an ultimate fact in Physiology, that cells have the power of growing from germs, of undergoing certain transformations, and of producing germs that will develope other cells similar to themselves;—just as it is an ultimate fact in Physics, that masses of matter attract each other; or in Chemistry, that the molecules of different substances have a tendency to unite, so as to form a compound different from either of the elements. It is of such ultimate facts as these, that the science of Vitality essentially consists; since the Physical and Chemical phenomena which occur in living bodies are not strictly removable from the laws of Inorganic Nature. The conditions under which this Assimilating power operates, however, are freely open to our investigation; and it is a great step in the progress of the inquiry, to become aware that these are so closely conformable, throughout the organized world, as they have been shown to be. It may be stated, as a general fact, that in assimilating, or converting into its own substance, matter which was previously unable to exhibit any of the manifestations of life, every cell thereby participates in the process of organization and vitalization; for, by the new circumstances in which the matter is placed, its properties undergo a change, —or, to speak more correctly, properties which were previously dormant are caused to manifest themselves. No matter, that is not in a state of organization, can exhibit those properties, which, from their being peculiar to living bodies, and altogether different from physical and chemical, are termed *vital;* and it may also be asserted that no matter which exhibits per-

fect organization is destitute of the peculiar vital properties belonging to its kind of structure.* As a corollary to this general fact, it may be stated, that no organism can be produced by any fortuitous combination of inorganic matter; since, even for the generation of the simplest cell, there is required a cell previously existing, to furnish the germ.

561. But this view also leads us to admit greater probability to the idea, that beings of the highest degree of organization may, by a perversion of their assimilating processes, give origin to those of a lower; and it is difficult to say that this is not the case in certain diseases with which the medical man is familiar. Thus, in the various forms of Cancer, it has been shown by Muller and others, that the new growth consists of a mass of cells, which, like the Vegetable Fungi, develope themselves with great rapidity, and which destroy the surrounding tissues by their pressure, as well as by abstracting from the blood the nourishment which was destined for them. These parasitic masses have a completely independent power of growth and reproduction; and it seems difficult to refuse them the title of distinct existences. They can be propagated by inoculation, which conveys into the tissues of the animal operated on the germs of the peculiar cells that constitute this morbid growth; and these soon develope themselves into a new mass. Several instances have been recently published of the occurrence of Vegetable organisms as parasites upon the Animal body; that in some of these a true Plant, possessing a regular apparatus of nutrition and reproduction, has arisen from a germ introduced from without, there can be little question; but in other instances (as in the case of the crusts of *Porrigo favosa*) it has been assumed that the organization is vegetable, because it consists of a mass of cells capable of extending themselves by the ordinary process of multiplication. But it must be remembered that the vesicular organization is common to Animals as well as to Plants; being the only form that manifests itself at an early period of development in either kingdom, and remaining throughout life in those parts which have not undergone a metamorphosis for special purposes. Hence to speak of *Porrigo favosa*, or any similar disease, as produced by the growth of a Vegetable within the Animal body, appears to the Author a very arbitrary assumption; the simple fact being, in regard to this and many other structures of a low type, that they present the simplest or most general kind of organization.†

562. From the previous details, it appears that Fibrin is so far prepared to pass into an organized condition, that simple contact with a living membrane is sufficient to cause the development in it of granular cytoblasts, and then of cells, which may be ultimately transformed into the most elevated kinds of organized structure; and that this tendency to organization is so strong, as to manifest itself even when it has been withdrawn in a fluid state from the vessels, or has remained in them after the loss of their vitality. There is some reason to believe that the nuclei of the exudation-cells are poured forth from the blood at the same time with the fibrinous matter; and that they are identical, either with the white globules of the blood, and with the corpuscles of the chyle and lymph (§ 566, 7), or with the nuclei of the

* For a fuller consideration of this question, and the grounds upon which this view is supported, the reader is referred to the Article *Life* in the Cyclopædia of Anatomy and Physiology, and to the Chapter on the Nature and Causes of Vital Actions in his Principles of General and Comparative Physiology.

† The Author is strongly inclined to believe that the propagation of many diseases by inoculation, essentially consists in the implanting of cell-germs from one animal in the body of another. The structure of the Vaccine Vesicle appears to him to point clearly to such a view.

red corpuscles of the blood (§ 576). Whichever view be correct, it is only referring the first aggregation of the granules by which these nuclei or cytoblasts are formed (as in Vegetables) to an earlier period in the assimilative process. With these general views, we shall now be prepared to enter in detail upon the consideration of that process.

Elaboration of Chyle and Lymph.

563. The *Chyle*, as first absorbed into the lacteals, is very different, both in its physical and chemical characters, from that which may be obtained from the larger absorbent trunks, and from the thoracic duct; for during its passage through these vessels and their ganglia or glands, it undergoes important alterations which gradually assimilate it to Blood. The chyle drawn from the lacteals that traverse the intestinal walls contains albumen in a state of complete solution (§ 453); and it is entirely destitute of the power of coagulation, no fibrin being present in it. The salts, also, are completely dissolved; but the oily matter presents itself in the form of globules of variable size.* It is generally supposed that the milky colour of the chyle is owing to these; but Mr. Gulliver has recently pointed out† that it is really due to an immense multitude of far more minute particles, which he describes as forming the *molecular base* of the chyle. These molecules are most abundant in rich, milky, opaque chyle; and in poorer chyle, which is semi-transparent or opaline, the particles float thinly or separately in the transparent fluid, and often exhibit the vivid motions common to the most minute molecules of various substances. Such is their minuteness, that, even with the best instruments, it is impossible to form an exact appreciation either of their form or their dimensions. They seem, however, to be generally spherical; and their diameter may be estimated at between 1-36,000th and 1-24,000th of an inch. Their chemical nature is as yet uncertain: they are remarkable for their unchangeableness when subjected to the action of numerous other reagents which quickly affect the chyle-globules; and they are readily soluble in ether, the addition of which causes the whole molecular base instantly to disappear, not a particle of it remaining; whence it may be inferred that they consist of oily or fatty matter. The milky colour which the serum of blood sometimes exhibits is due to an admixture of this molecular base; it is most common in young animals that are suckling; but it is not uncommon in adults, and is not to be attributed to an absorption of milk into the chyle, as the physical properties of the two are quite different.

564. During the passage of the chyle through the absorbents on the intestinal edge of the mesentery, towards the mesenteric glands, its character changes in several important particulars. The presence of fibrin begins to manifest itself, by the slight coagulability of the fluid when withdrawn from the vessels; and while this ingredient increases, the albumen and the oil-globules gradually diminish in amount. The chyle drawn from the neighbourhood of the mesenteric glands exhibits the globules regarded as characteristic of that fluid; these are peculiarly abundant in the fluid drawn from the glands themselves; and they are constantly found in it, through its whole subsequent course. It has been pointed out by Mr. Gulliver that there is a

* These oily globules are more abundant in the Chyle of Man and of the Carnivora, than in that of the Herbivora; their diameter has been observed to vary from 1-25,000th to 1-2,000th of an inch.

† Dublin Medical Press, Jan. 1, 1840, and Gerber's General Anatomy, Appendix, p. 88.

remarkable similarity between the chyle-globules obtained from the mesenteric glands, and the characteristic granules of the Thymus gland (Chap. XII.). The chyle-globules are much larger than the molecules just described, and an examination of their characters presents no difficulty. Their diameter varies from 1-7110th to 1-2600th of an inch; the average being about 1-4600th. They are usually minutely granulated on the surface, seldom exhibiting any nuclei, even when treated with acetic acid; but sometimes three or four central particles may be distinguished within them. During the passage of the chyle through the mesenteric glands, a further increase in the proportion of fibrin takes place; and the resemblance of the fluid to blood becomes more apparent. The chyle drawn from the vessels intermediate between these and the central duct, possesses a pale reddish-yellow colour; and, when allowed to stand for a time, undergoes a regular coagulation, separating into clot and serum. The former is a consistent gelatinous mass, which, when examined with the microscope, is found to include the chyle-globules, each of them being surrounded by a delicate film of oil: the fibrin of which it is principally composed differs remarkably from that of the blood in its inferior tendency to putrefaction; whence it may be inferred that it has not yet undergone its complete vitalization. The serum contains the albumen and salts in solution, and a proportion of the chyle-globules suspended in it. It is curious, however, that considerable differences in the perfection of the coagulation, and in its duration, should present themselves in different experiments. Sometimes the chyle sets into a jelly-like mass, which, without any separation into coagulum and serum, liquefies again at the end of half an hour, and remains in this state. This change takes place in the true coagulum also, if it be kept moist for a sufficient length of time. The chyle from the receptaculum and thoracic duct coagulates quickly, often almost instantaneously; and few or none of the globules remain in the serum.

565. It is to be remembered that the lacteals are the lymphatics of the intestinal walls and mesentery, performing that function of interstitial absorption, which is elsewhere accomplished by vessels that are not concerned in the introduction of alimentary substances from without. During the intervals of digestion, they contain a fluid which is in all respects conformable to the lymph of the lymphatic trunks. The aspect of the lymph greatly differs from that of the chyle, the former being nearly transparent, whilst the latter is opaque or opalescent; and this difference is readily accounted for, when the assistance of the microscope is sought, by the entire absence from the lymph of that molecular base which is so abundant in the chyle. A considerable number of globules are generally present in it; and these seem to correspond in all respects with those of the chyle. Their amount, however, is extremely variable; as is also that of the oil-globules, which sometimes occur, whilst in other instances none can be discovered. Lymph coagulates like chyle; a colourless clot being formed, which encloses the greater part of the globules.

566. The nature and source of the peculiar globules of the lymph and chyle, is as yet a matter of doubt; some light, however, has been thrown on their history, by recent investigations; and much may be said of them, which, if not absolutely proved, can scarcely be regarded as improbable. The process of their formation bears a striking analogy to that of the cytoblasts of Plants, as observed by Schleiden (§ 556). They appear in the midst of a fluid crowded with minute granules, and appear to be themselves composed of an aggregation of smaller particles. That the chyle-globules are not identical in chemical composition with the molecular base

is quite certain, from the completely different effects of re-agents upon the two respectively; but it may be surmised that, as they appear to consist of an altered form of albumen, the soluble albumen and the fatty matter are both concerned in their production. It has been stated that, whilst the fibrin increases, the oil-globules undergo an evident diminution (§ 564), and that the quantity of albumen lessens. It is not conceivable that the fibrin should be at once formed at the expense of the oil-globules; since albumen, which is a mere chemical compound, ready to undergo organization and vitalization, is always the preceding grade. The fibrin must, therefore, be produced at the expense of the albumen; whilst new albumen is elaborated from the oily matter. Of the process by which the latter important change is accomplished, we are yet entirely ignorant; but the important alteration which takes place in the proportion of azotized ingredients clearly shows, that nitrogen must be in some manner communicated to the chyle during its progress along the lacteals. No source for this nitrogen can be suggested except the blood; and the influence of the blood upon the contents of the absorbent vessels must be in part communicated through the *vasa vasorum* distributed upon their walls (since in the cold-blooded Vertebrata there are no lymphatic glands), but chiefly in the lymphatic glands, where the blood-vessels and absorbents come into extremely close relation. The idea that the blood is deprived, in the mesenteric vessels, of some of its azote, derives important confirmation from the fact, that the secretion of the Liver, which is chiefly formed from blood that has returned form these vessels, consists almost entirely of unazotized ingredients (Chap. XII.). It may be conceived, then, that whilst the albuminous matter originally present in the chyle is being converted into fibrin, new albumen is being formed at the expense of the fatty matter; and it is probably of this last that the chyle-globules are composed. The same account is applicable to the lymphatics, a part of whose function it is to bring the oily matter stored up in the adipose tissue within the sphere of the nutritive operations (§ 465); and the variation in the circumstances which may render this necessary, fully accounts for the variation in the amount of oily and albuminous globules presenting themselves in this fluid.

567. Regarding the ultimate destination of these globules, the very interesting speculation has been recently offered,—that they are the nuclei or cytoblasts of the primordial cells, from which all the tissues originate.* If this be true, their analogy, both in their function and in their mode of origin, with the vegetable cytoblasts is complete. It has been frequently suspected that they are identical with the nuclei of the blood-corpuscles; but this idea is rendered inadmissible, as far at least as regards Mammalia, by the respective sizes of these objects; the lymph-globules being often as large as the entire corpuscles, and sometimes even larger. The circulating fluid may be distinctly seen, in Frogs and other Reptiles, to contain white globules, sometimes in great numbers; these move very slowly along the walls of the vessel, in a stratum of fluid which seems in part adherent to them; but they are sometimes detached, and carried along in the rapid current of the blood-discs. These globules cannot be distinguished from those of the lymph drawn from the lymphatics of the same animal. In Mammalia, however, the existence of lymph-globules in the blood is less certain. If a drop of human blood be carefully examined with a deep object-glass, one or two white globules, the average diameter of which is about 1-2900th of an inch, will generally be seen in each field of vision; they are spherical

* Gulliver in note to Gerber's Anatomy, p. 83.

withdrawn from the living vessels; and the appearance of distinct organization in this fibrin, especially when its concretion has taken place in contact with a living surface. These facts, with many others, appear to indicate that fibrin is the material which is applied to the nutrition of the tissues; and that albumen can only be thus employed after passing through the condition of fibrin. The difference between the two is precisely analogous to the difference between the ordinary mucilage of plants, and that peculiar glutinous sap which is found wherever a formation of new tissue is taking place, and which, like the liquor sanguinis of the animal, is spontaneously coagulable and disposed to pass of itself into a semi-organized condition.

The change from albumen to fibrin is, therefore, the first important step in the process of assimilation. It commences in the absorbent system; for the chyle is found to contain fibrin even before it enters the mesenteric glands; and after it has passed through them the amount of fibrin is much increased. It continues in the blood, for the quantity of fibrin is always kept up in health to a certain standard, although there must be a continual withdrawal of it for the nutritive processes, without a correspondingly regular supply; and it is found to undergo a sudden and remarkable increase under the influence of local causes. What is the cause of this change? It has been usually attributed to some influence effected upon the albuminous fluid by the living surfaces over which it is passing; and the increase in the amount of fibrin in the chyle which is speedily noticed after its passage through the mesenteric glands, has been thought due to some peculiar action of the blood that may come into relation with it, through the thin walls of that capillary plexus which forms, with the convoluted lacteal tubuli, nearly the whole bulk of those glands. Perhaps, however, it may be possible to offer a more satisfactory explanation; one, at least, which shall be conformable to phenomena observed in other cases.

Several examples have already been mentioned of the transient existence of cells, that grow, arrive at maturity, and then disappear; apparently without performing any particular function. Thus in the albumen of the seed, this often takes place to a remarkable extent. In the yelk of the egg there is a similar transitory development of cells, of which several generations succeed each other, without any permanent structure being the result. In the germinal vesicle, again, several annuli of temporary cells are seen to occupy its cavity; and the oldest and largest of these contain another generation; yet all these disappear by liquefaction, as soon as the two permanent cells begin to be developed in the centre. Further, in the subsequent development of all the cells which are descended from these, the same process is repeated, a great number of cells being produced, only to liquefy again as soon as the two central cells make their appearance. Now is it to be supposed that all this *cell-life* comes into existence without some decided purpose? I think the physiologist would not be justified in assenting to such an idea, even if he could assign no obvious reason for the process. But if an object can be assigned, which is conformable to what we elsewhere know of the operations of cells, it may claim to be received as a sufficient explanation, until some better one can be offered. Such an explanation may, I think, be deduced from the foregoing facts, and others of like nature.

It has been seen that the first union of the inorganic elements into the simplest proximate principles, is effected by the *cell-life* of plants. The change of these principles into the peculiar compounds which form the characteristic secretions of plants, is another result of their cell-life. And the elaboration of those azotized principles which do not enter into th

that the latter are the germs of the chyle-cells; and I have little doubt that this idea is correct. These reproductive granules, however, must have been produced by some previously existing cell; and their most probable origin appears to me to be the cells already mentioned as the *selectors* of the chyle at the extremities of the villi. These cells, in bursting or liquefying, yield both their fluid contents, and their reproductive granules, to the absorbent vessels; and in these vessels the chyle appears destined to undergo a gradual alteration, under the influence of that cell-life of which the foundation is laid at the first reception of the fluid into the system. The development of these cells, and the production of their peculiar effects, require a certain time; this is provided for by the delay of the chyle in the lacteal vessels. In the lower Vertebrata, there are no mesenteric glands,—a circumstance which indicates that these are not an *essential* part of the absorbent system; but, in such animals, the absorbents are immensely extended in length. In the warm-blooded Vertebrata, in whose conformation the principle of concentration operates to the greatest extent, we see no such prolongation; but it is provided for by the excessive convolution of the vessels in the mesenteric glands, where it seems probable that the chyle is delayed during the development of its characteristic cells.

Statements of a precisely similar kind may be made, regarding the lymph and its corpuscles. Reasons have been elsewhere given by the author, for regarding the lymph, not as a fluid destined to be thrown out of the system, but as the product of that secondary digestion, by which a portion of the materials, that have formed a component part of the tissues and have been set free by their disintegration, are again rendered subservient to nutrition, and are reconveyed into the current of the circulation, (§ 465–67.) One thing appears certain,—that, with the exception of fatty matter (of which the chyle contains a large amount, whilst the lymph presents scarcely a trace of it), there is little appreciable difference between the chyle and the lymph. The latter, like the former, contains albuminous matter, part of which undergoes a gradual transformation into fibrin; and there is precisely the same evidence as in the former case, that this change is effected by the development of cells in the fluid. The idea which we should hence form, that the lymphatic glands are organs of nutrition, in which the matters passing through them are subjected to an elaboration which prepares them for the growth and maintenance of the animal structures, entirely agrees with Mr. Gulliver's observations. (See Appendix to Gerber, pp. 97-8.)—C.]

Physical and Vital Properties of the Blood.

570. The blood, whilst circulating in its vessels, is composed of a fluid, in which a large number of corpuscles or particles of a red colour are suspended. The fluid portion, which is known under the name of *liquor sanguinis*, essentially consists of fibrin and albumen with saline matter dissolved in water; and this, when effused without an intermixture of corpuscles, is known under the name of coagulable lymph. The blood-particles (commonly, but erroneously, termed *globules*) are flattened discs, which in Man and most of the Mammalia have a distinctly circular outline. In the discs of Human blood, when examined in its natural condition, the sides are somewhat concave; and there is a bright spot in the centre, which has been

palpable that nothing similar has yet been detected in any other animal fluid. The larger, more unequal-sized, and highly refracting oily globules of the chyle are in a very different state, and so are those of milk or cream.

We have thus a class of facts, which indicates that the conversion of the chemical compound into the organizable principle,—such as mucilage into elaborated sap, or albumen into fibrin,—is effected in particular situations by the vital agency of transitory cell-life; that is, by the production of cells which are not destined to form an integral part of any permanent structure, but which, after attaining a certain maturity, reproduce themselves, and disappear,—successive generations thus following one another, until the object is accomplished, after which they altogether vanish. We shall now consider another class of facts, which seems to indicate that the same change is continually being effected in the chyle, lymph, and blood of animals, as well as in the proper juice of plants; by cells, which are either carried about with it, or which are developed for the purpose in particular situations.

In chyle drawn from the lacteals near the intestinal tube, there is but little appearance of organization, very few chyle corpuscles being here seen; but a large amount of very minute molecules, having apparently a fatty character, are diffused through it.* In the chyle of the mesenteric glands, the corpuscles are extremely numerous; and they are always readily seen in the chyle of the central lacteals, and of the receptaculum chyli and thoracic duct; although their number is considerably less than in chyle drawn by pricking the lacteals of the mesenteric glands. The average size of these corpuscles is about the 1-4600th of an inch; but they vary from about 1-7000th to 1-2600th. They are evidently imperfectly formed cells, which are frequently seen to contain two or three central molecules, or a granular matter, especially after they have been treated with water, and which usually exhibit the appearance of a single round nucleus when treated with dilute muriatic acid: but in the largest corpuscles, obtained from the thoracic duct, the addition of acetic acid sometimes discloses three or four central particles, similar to those which may be frequently seen by the aid of this acid in the white globules of the blood; such corpuscles may, I think, be considered as in the act of producing new cells. This idea is confirmed by the fact communicated to me by Mr. Gulliver, that the central particles of the larger chyle-globules, like the same nuclei of the colourless globules of the blood, are rather larger, more distinct, and disc-like, than the central molecules of the common-sized chyle and lymph-globules. Now the first appearance of these cells in large number is exactly coincident with the first appearance of fibrin in the chyle, to an amount sufficient to produce spontaneous coagulation; and when this fact is connected with those which have been previously stated, the inference seems very probable, that the elaboration of the fibrin is a consequence of the production of these cells, and of their vitalizing influence upon the albumen.

With regard to the origin of these cells, there is ample room for difference of opinion. Among the minute particles contained in the chyle of the peripheral lacteals, some appear to be (from their solubility in ether) of an oily character;† whilst others are albuminous. It is considered by Wagner

* See Mr. Gulliver's observations on the chyle, &c., in Appendix to translation of Gerber's General Anatomy pp. 88–94.

† That the molecular base of the chyle may be of an oily nature, there is reason to believe from Mr. Gulliver's observations (Note to Gerber, p. 56), but the remarkably uniform, grayish ground, which this base presents in the field of vision, the singular uniformity in the size of the constituent molecules, their ready disappearance on the addition of a small quantity of cold ether to the fluid chyle, and the appearance in this mixture of a fluid matter, as described by Dr. Rees, would indicate that the molecular base must be either a peculiar variety of fatty matter, or fatty matter in a peculiar condition,—perhaps in the form of an emulsion, so fine and im-

that the latter are the germs of the chyle-cells; and I have little doubt that this idea is correct. These reproductive granules, however, must have been produced by some previously existing cell; and their most probable origin appears to me to be the cells already mentioned as the *selectors* of the chyle at the extremities of the villi. These cells, in bursting or liquefying, yield both their fluid contents, and their reproductive granules, to the absorbent vessels; and in these vessels the chyle appears destined to undergo a gradual alteration, under the influence of that cell-life of which the foundation is laid at the first reception of the fluid into the system. The development of these cells, and the production of their peculiar effects, require a certain time; this is provided for by the delay of the chyle in the lacteal vessels. In the lower Vertebrata, there are no mesenteric glands,—a circumstance which indicates that these are not an *essential* part of the absorbent system; but, in such animals, the absorbents are immensely extended in length. In the warm-blooded Vertebrata, in whose conformation the principle of concentration operates to the greatest extent, we see no such prolongation; but it is provided for by the excessive convolution of the vessels in the mesenteric glands, where it seems probable that the chyle is delayed during the development of its characteristic cells.

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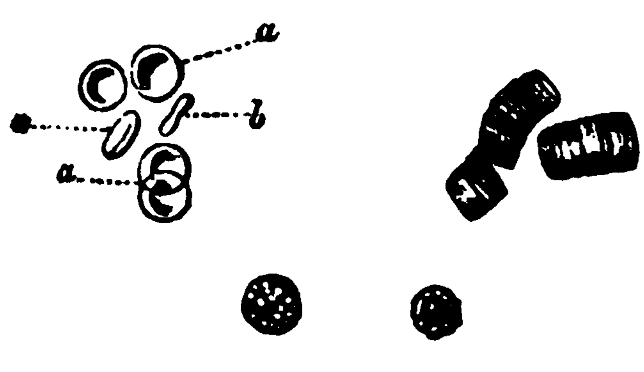
palpable that nothing similar has yet been detected in any other animal fluid. The larger, more unequal-sized, and highly refracting oily globules of the chyle are in a very different state, and so are those of milk or cream.

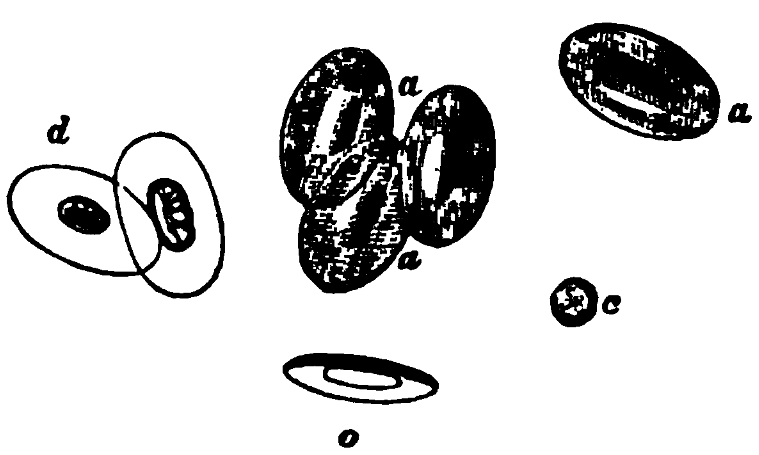
regarded by many as indicating the existence of a nucleus, although it is in reality due simply to the greater thinness of the disc at that part. The form of the disc is very much altered by various reagents; for the membrane which composes its exterior is readily permeable by fluids; so that, if the discs be put into water, a powerful endosmose takes place towards the interior, causing the particles to assume a globular form. Hence in examining the blood, it is necessary to dilute it with a fluid as nearly as possible of the same character with ordinary serum.* In regard to the existence of a nucleus in the corpuscles of Mammalia, there is considerable difference of opinion amongst microscopists; some maintaining that it can be brought into view by treating them with acetic acid, whilst others deny that any definite appearance is thus produced. The Author is inclined, from his own observations, to believe that it exists; and the most recent statements in regard to it seem very unequivocal.† In the red particles of the Frog, which are far larger than those of Man, a nucleus can be observed to project somewhat from the central portion of the oval, even during their circulation; and it is rendered extremely distinct by the action of acetic acid; this dissolves away the remainder of the particle, and gives an increased opacity to the nucleus, which is then seen to consist of a granular substance. In the still larger blood-disc of the Proteus and Siren, this appearance is yet more distinct, the structure of the nucleus being so evident without the addition of acetic acid, that its granules can be counted.‡

Fig. 53.



Corpuscles of human blood magnified about 500 diam. A, single particles; *a*, *a*, their flattened face; *b*, a particle seen edgeways. B, aggregation of particles in a columnar form. (After Wagner.)

Fig. 54.



Particles of *Frog's* blood; *a*, *a*, their flattened face; *b*, particle turned nearly edgeways, *c*, lymph-globule; *d*, blood-corpuscles altered by dilute acetic acid. Magnified 500 diam. (After Wagner.)

* By Wagner, the filtered serum of frog's blood is recommended for this purpose. Weak solutions of salt or sugar, and urine, answer tolerably well; but Mr. Gulliver remarks that all addition must be avoided when it is intended to measure the corpuscles, or to ascertain their true forms; as the serum of one mammal reacts injuriously on the blood of another. See Philos. Magaz. Jan. and Feb. 1840.

† See Dr. Barry's Observations on the Corpuscles of the Blood, Philos. Transact. 1841, Part II.

‡ As Professor Owen's interesting account of the blood-discs of the Siren may not be generally accessible (Penny Cyclopædia, Art. *Siren*) the leading facts in it will be here stated. This animal agrees with the Proteus and other species in being perennibranchiate (§ 43); and, as in all its congeners yet examined, the blood-discs are of very large dimensions. They are usually of an oval form, the long diameter being nearly twice the short; and the nucleus projects slightly from each of the flattened surfaces. Considerable variety in the form of the disc presented itself, some of the corpuscles being much less oval than others; but the nucleus did not partake of these variations in nearly the same degree. The nucleus is clearly seen to consist of a number of moderately-bright spherical granules, of which from 20 to 30 could be seen in one plane or focus, the total number being of course much greater. When removed from the capsule, the nuclei are colourless, and the component granules have a high refracting power. Viewed *in situ*, they present a tinge of colour lighter

571. In regard to the *form* of the blood-corpuscles, it is a fact of much interest, that in all oviparous air-breathing Vertebrata they are oval, whilst in Mammalia they are round, with the exception of the family of Camelidæ, in which they are oval. Their form is not unfrequently seen to change during their circulation; but this is generally in consequence of pressure; from the effects of which, however, they quickly recover themselves. In the narrow capillary vessels, they sometimes become suddenly elongated, twisted, or bent, through a narrowing of the channel; and this may take place to such a degree as to enable the disc to pass through an aperture which appears very minute in proportion to its diameter.* Even when withdrawn from the vessels, however, and floating in their own serum, the discs are frequently seen to undergo remarkable changes in form, which cannot be attributed to endosmose or exosmose, and which indicate the existence of a property of contractility in their own parietes. These changes appear to take place especially in the corpuscles of blood whose vitality is heightened by a local action; they have been minutely described by Dr. Barry, who has witnessed them in the blood effused on the inner membrane of the Fallopian tube of the Rabbit at the time of the transit of the ovum; and they have also been observed by Mr. Gulliver in blood that has been extravasated. In the instances recorded by Dr. Barry, the changes of form were often so rapid as to produce evident movements. When undergoing spontaneous decomposition, the blood-discs become granulated, and sometimes (as long ago noticed by Hewson) even mulberry-shaped; and particles in which these changes appear to be commencing may be found in the blood at all times.

572. The size of the blood-discs is liable to considerable variation, even in the same individual; and this is at once understood, when they are considered as cells in different stages of growth. There are, however, limits to this variation for each species; and the blood-discs of one tribe of Mammalia can rarely be confounded with those of another. The diameter of the corpuscles bears no constant relation to the size of the animal, even within the limits of the same class; thus, although those of the Elephant are the largest among Mammalia (as far as is hitherto known), those of the Mouse tribe are far from being the smallest, being in fact more than three times the diameter of those of the Musk Deer. There is, however, a more uniform relation between the size of the animal and that of its blood-discs, when the comparison is made within the limits of the same order. In Man, the diameter varies from about 1-4000th to 1-2800th; the average diameter is probably about 1-3400th. This is very nearly the same with the average of the *Quadrumana;* there is, however, a slight diminution among the Lemurs, and there is more variation among them than among the Monkeys. Among the *Cheiroptera*, the diameter of the corpuscles is somewhat less than in the preceding order, the average being about 1-4300th of an inch. The blood-discs of the Mole are still smaller, averaging only the 1-4750th of an inch; those of the Hedge-hog, however, are larger, being about 1-4100th. Among the Plantigrade *Carnivora*, the average is about

than that of the surrounding fluid, and dependent upon the thin layer of that fluid interposed between the nucleus and the capsule. As the fluid contents of the blood-disc in part evaporate during the process of desiccation, the capsule falls into folds in the interspace between the nucleus and the outer margin; these folds generally take the direction of straight lines, three to seven in number, radiating from the nucleus.

* Blood-corpuscles are repeatedly found, quite unaltered in appearance, on the mucous surfaces, when no solution of continuity whatever can be detected in the vessels." Gulliver, in Gerb. Gen. Anat. p. 78.

1-3800th, and from this none depart very widely: but among the Digitigrade species there is a considerable range; in the Weasel tribe, the average is about 1-4800th; in the Feline, it is about 1-4400th; in the Dog tribe,* there is a range of averages from 1-3400th to 1-4100th; and in the Seal, the average is about 1-3300th. Observations on the blood-discs of the Cetacea are much required. Among the *Pachydermata*, the average, excluding the Elephant (the diameter of whose blood-discs is about 1-2745th of an inch), and the Rhinoceros (in which they are about 1-3765th), may be stated at about 1-4200th; and there is less variation than might have been expected from the different size and conformation of the several species examined. Among the *Ruminantia*, the corpuscles are for the most part smaller than in other orders; and there is more relation between their diameter and the size of the animal, than is elsewhere observable. Excluding the Camelidæ (which are zoologically intermediate between the Ruminantia and Pachydermata), we find a range of sizes extending from the 1-3777th to the 1-12325th of an inch; the former is the diameter in one of the larger Deer; the latter in the Musk Deer, which is the smallest of the whole order. In the Camel tribe, the average long diameter of the oval corpuscles is 1-3400th of an inch; whilst that of the short diameter is 1-6300th; and this is nowhere widely departed from: the length of the discs is, therefore, not quite twice their breadth. Among the *Rodentia*, the discs are rather large, especially considering the small size of most of the species. In the Capybara, which is the largest animal of the order, they average 1-3216th; and in the Mouse family (the smallest of Mammalia) they are as much as 1-3800th. In the Squirrel, the diameter is rather less; but in scarcely any of the whole order is it under 1-4000th. Among the *Edentata*, the only species yet examined is one of the Armadillos, in which the diameter of the corpuscles is about the same as in the Quadrumana. In the *Marsupialia* the range is nearly the same as among the Rodentia.

573. In Birds, according to the observations of Mr. Gulliver, the long and short diameters of the corpuscles usually bear to each other the proportion of 1½ or 2, to 1; and this is the general relation among oviparous Vertebrata, with the exception of some of the Crocodile tribe, in which the length is sometimes three times the breadth. The size of the corpuscles of Birds has generally more relation to that of the species, than in Mammalia. No instance has yet been detected of the occurrence of comparatively small corpuscles in the larger species, and of large corpuscles among smaller animals, which has been seen to be common among the former class; the blood of the Humming-birds, however, has not yet been examined. The largest discs are found among the *Cursores;* those of the Emu have an average long diameter of 1-1690th of an inch, and a short diameter of 1-3030th; and among the larger *Raptores*, *Grallatores*, and *Natatores*, the dimensions are but little inferior. The least dimensions hitherto observed are among the small Passerine birds; in which the corpuscles have a long diameter of about 1-2400th of an inch, and a transverse diameter of from 1-3800 to 1-4800th. Circular discs may be occasionally observed in some species, agreeing with the others in every particular but their form; and every gradation may be noticed between these and the regular oval cor-

* Two facts of much interest in Zoology have been brought to light by Mr. Gulliver's examination of the diameter of the blood-corpuscles of this tribe. The difference between those of the Dog and Wolf is not greater than that which exists among the varieties of the Dog, whilst the discs of the Fox are much smaller. The discs of the Hyæna are far more approximate to those of the Canidæ than they are to those of the Felidæ.

puscles. The nuclei of the blood-particles of Birds are very distinctly brought into view, when they are treated with acetic acid.

574. The large size of the blood-discs in Reptiles, especially in Batrachia, and above all, in the perennibranchiate species of the latter, has been of great service to the physiologist, by enabling him to ascertain many particulars regarding their structure, which could not have been otherwise determined with certainty. Among other facilities which this occasions, is that of procuring their separation from the other constituents of the blood; for they are too large to pass through the pores of ordinary filtering-paper, and are therefore retained upon it, after the liquor sanguinis has flowed through. The blood-discs of the warm-blooded Vertebrata cannot be thus separated. The oval corpuscles of the Frog have a long diameter of about 1-1000th, and a transverse diameter of about 1-1800th of an inch; those of the Salamander or Water-newt, are rather smaller. The long diameter of the corpuscles of the Proteus is stated by Wagner at 1-337th of an inch; that of the Siren is about 1-435th, the short diameter being about 1-800th of an inch: the extremes of variation, however, are very wide. The long diameter of the nuclei is about 1-1000th or 1-1100th, and the short diameter about 1-2000th; hence it is about three times as long, and nearly twice as broad, as the entire human blood-disc, thus having six times its superficies; its thickness is about 1-3800th of an inch.

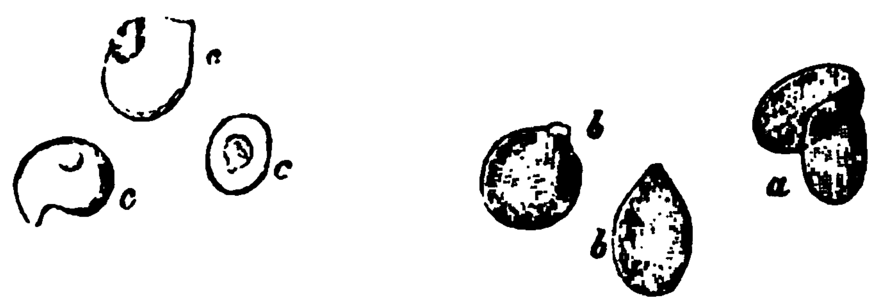
575. In regard to the Chemical constitution of the blood-corpuscles, it is difficult to speak with definiteness; since there are three parts in each disc which are essentially different in character, and which may have a very different composition. These parts,—the capsule, the nucleus, and the contained matter, cannot be separated without the use of chemical reagents, which must alter their respective properties. Two proximate principles have been obtained from the blood-discs: these are designated as hæmatosine and globuline. To the former, the red colour of the blood is due, although it constitutes not more than a 20th or 25th part of the whole mass of dried globules. When separated from the globulin, it is of a dark-brown hue, and is tasteless and insoluble in water, alcohol, and ether; but is readily soluble in water or alcohol that contains alkalies or acids, whence it may be supposed to unite with these, like albumen, as an acid or a base. In composition, however, it differs considerably from both protein and albumen, its formula being 44 C, 22 H, 3 N, 6 O, with a single proportional of iron. When burned, it yields a notable quantity of peroxide of iron; and one atom of this is considered to be present in combination with one of the animal compound, which is analogous to protein. The red colour is not due, however, as formerly supposed, to the presence of this peroxide; for M. Scherer has recently found that the metal may be entirely dissolved away by the agency of acids, and that the animal matter, afterwards boiled in alcohol, colours the spirit intensely red. The *globulin*, which is the principal constituent of the corpuscles, has not yet been isolated; but from its properties in combination, it is inferred to differ but little from protein. It may perhaps be doubted, whether these two principles have a separate existence, or whether they are not rather results of the chemical processes employed to obtain them. When the blood-discs are separated from the other constituents of the fluid, and are immersed in water, they soon absorb so much as to become globular; and the continuance of the endosmose occasions the diffusion of their contents (perhaps by the rupture of the capsule) through the water, in which the greater part dissolves. This solution exhibits the same changes of colour under the influence of oxygen, acids, saline matter, &c., as the blood undergoes in similar circumstances (§ 542).

When it is heated, the matter of the globules is coagulated and forms an insoluble precipitate; both in its soluble and coagulated states, it exhibits similar effects with reagents, as does albumen in the same conditions.

576. The question of the *origin* of the Blood-corpuscles is a very interesting one, and cannot yet be regarded as fully elucidated. That they are to be regarded as nucleated cells, conformable in general character with the isolated cells which constitute the whole of the simplest Plants (§ 555), and having each an independent life of its own, there can now be no reasonable doubt. From this we should infer that they have the power of reproducing themselves; and the recent observations of Dr. Barry and other microscopists have confirmed the statement long ago made to that effect by Leeuwenhoek. The first change which takes place is the appearance of delicate radiating lines between the nucleus and the periphery; dividing the disc into several segments, usually six in number (Fig. 22, Plate I). The margin is soon observed to become crenated, by indentations at corresponding points; and these indentations become deeper, until a complete separation takes place, forming six young cells or discs (*a*, *b*, *c*, *d*, *e*.) It is next to certain that these are developed within the parent cell or disc, from some of the granules on the margin of its nucleus; just in the same manner as rings of cells will be hereafter described as arising from the germinal spot. From this fact, connected with what has been already stated of the continual decomposition of the blood-discs (§ 571), we may infer that each cell has a determinate period of existence; and that, whilst some are decaying from age, their place is being supplied by young ones in process of growth. Between the small newly-generated disc, and the full-sized corpuscle, we should expect to find every intermediate size; and this is exactly what presents itself. That the corpuscles may be generated with great rapidity under peculiar circumstances, will hereafter appear (§ 494); and their amount may undergo a rapid diminution also, without any evident abstraction of them from the circulating fluid. In regard to the question whether or not the blood-discs can be produced from the chyle-globules, it is difficult to speak positively. Appearances have been seen by Wagner, Gulliver, and others, in the blood of Batrachia, which seem to indicate that the latter serve as the nuclei of cells, which, when fully developed, may become blood-discs; but in the Mammalia it is scarcely possible to imagine that this can occur; since the diameter of the colourless globules is so constant, whilst that of the blood-discs is so variable, that the former, though sometimes the smaller, are in other instances far larger than the latter.

577. That the blood-discs when first formed in the embryo have an origin common to that of all other tissues, cannot be doubted. They are produced, in the embryo of the Bird, in the portion of the germinal membrane, which afterwards becomes the area vasculosa; this consists of delicate cells very uniformly disposed; and whilst capillary vessels are being formed by the union of the cavities of these, blood-discs are developed from the granules or cell-germs they contain. These changes take place about the second or third day of incubation; but it is not until some days afterwards that the discs assume their characteristic form. As at this period no special organs exist in the embryonic structure, it is evident that the blood must be formed by the cells of the germinal membrane, at the expense of the albuminous alimentary materials which they absorb from the yelk; hence we may infer that no special organ can be needed for this purpose in the adult, and that the assignment of the manufacture of blood-corpuscles, by some physiologists to the Spleen, by others to the

Fig. 55.



Production of blood-corpuscles in Chick, on the fourth day of incubation; *a*, particles fully-formed; *b*, particles in progress of formation; *c*, similar particles altered by dilute acetic acid, so as to display their nuclei. (After Wagner.)

Thymus, must be incorrect. The corpuscles are generally larger in the embryo than in the adult, especially soon after the period of their first formation; it was remarked by M. Prevost that in the fœtal goat they were at first twice the size of those of the mother. Mr. Gulliver has observed, however, that at a later period of utero-gestation they are sometimes smaller than the average dimension of the adult; but perhaps all such observations are to be received with hesitation, owing to the fact mentioned by him, that the variety in the magnitude of the fœtal corpuscles is much greater than in the full-grown animal.

[Regarding the origin of the colourless corpuscles there is a similar diversity of opinion; by Müller and many other physiologists, they are considered to be identical with the lymph and chyle-corpuscles; and to this view the author is himself inclined. It is a very strong argument in favour of it that they are of nearly the same size and appearance in all animals that have yet been examined; and that they correspond very closely, not only in these respects, but in the mode in which they are influenced by reagents. There does not seem any greater difference between the colourless corpuscles of the blood and the chyle or lymph-globules, than there is between chyle-globules taken from the different parts of the lacteal system. On the other hand, Dr. Barry and Mr. Addison agree in the opinion that the colourless corpuscles are formed from the central portion of the red discs; and they consider them as holding an intermediate position between the true red discs and those greatly altered forms of them which constitute (according to them) the foundations of the tissues, as well as pus and other globules. It does not appear to the Author that the facts stated by either of these observers are sufficient to establish a position so much at variance with known facts. There seems as much difficulty in imagining that the colourless corpuscles of the Frog should have originated from its comparatively *large red* corpuscle,* as that the minute red corpuscle of the Musk Deer should have had its origin in the comparatively large lymph-globule of that interesting animal.† The circumstance that colourless corpuscles exist abundantly in the blood of the fœtus, which has no separate chyle, does not weigh in the least against the doctrine of the identity of the chyle and colourless corpuscles; since the fluid taken up by the omphalo-mesenteric vessels from the surface of the yelk-bag, or from the placental sinuses by the umbilical vessels, stands precisely in the same relation as chyle. The cell-germs of the former

* Dr. Barry has informed the author that he feels well assured of this transformation; but it cannot be the same with that which produces the colourless corpuscles of the mammalia.

† See Mr. Gulliver's observation, in Willis's Translation of Wagner's Physiology, p. 251, note.

are probably furnished by the cells that intervene between the omphalo-mesenteric vessels and the surface of the yelk; those of the latter by the similar layer of cells that covers (according to Mr. Goodsir's observation) the extremities of the absorbent tufts of the umbilical vessels.]—C.

578. In regard to the uses of the blood-corpuscles in the animal economy, there is no doubt that much remains to be learned. A speculative opinion has long enjoyed a certain degree of currency,—that some of the tissues, especially the muscular (in which alone fibrin was supposed to exist), were formed by the aggregation of them in various modes; and this opinion has lately been revived in an altered form by Dr. Barry, as the result of actual observation.* According to his most recent statement, he has found every tissue which he has examined "to arise out of corpuscles having the same appearance as the corpuscles of the blood." This statement includes Epithelium-cells, Pigment-cells, Capillary-vessels, the elements of Cellular tissue, of Cartilage, of Muscular tissue, of Nervous tissue, of the Crystalline Lens, of the Chorion, of the Ovulum, of the Spermatozoon, and of the Pus-globule. The Author deems it premature, however, to adopt so important a conclusion as an established physiological truth, until it has been tested by observations of a more varied kind. These should be made upon animals having very large blood-discs (such as the perennibranchiate Batrachia) and upon those in which they are extremely minute (such as the Napu Deer). It is only by observations of this kind, that the relation between the blood-disc and the exudation-corpuscle can be fully determined; and whether the latter originates, as Dr. B. supposes, in the nuclei of the red particles, or is rather an altered form of the chyle globule, must be considered an undecided question. That the various simpler forms of tissue may be produced from the exudation-corpuscles, is indubitable; and the want of correspondence between the dimensions of the elements of these, in different animals, and the size of the blood-discs, may be thought to indicate that their relation is not so close as Dr. B. supposes.—The red particles are most abundant in animals which maintain the highest temperature; thus, they are somewhat more numerous, in proportion to the whole bulk of the blood, in Birds than in Mammalia, and far more in the latter than in Reptiles and Fishes. As it is evident that they undergo very important changes in the pulmonary and systemic capillaries, their colour being changed from purple to red in the former, and from red to purple in the latter, it may perhaps be surmised without improbability, that they have for a principal office the introduction of oxygen into the blood that circulates through the systemic capillaries, and the removal of the carbonic acid set free there;—to serve as the medium, in fact, for bringing the tissues into relation with the air, the influence of which is necessary for the maintenance of their vital activity. It is not unlikely, also, that they may thus be of important assistance in promoting the movement of the fluid in which they are suspended; for, if it be true that this partly depends upon the chemical condition of the blood in respect to the tissues which it supplies, any attractions or repulsions arising out of this may be more powerfully exercised upon a solid corpuscle, than upon the constantly-shifting particles of the fluid.

579. The existence of white or colourless corpuscles in the circulating blood of Frogs, and the probable identity of these with the lymph or chyle-globules, has been already mentioned (§ 567). The nature of the white particles in the blood of Mammalia is still a subject for inquiry; by Dr.

* Philosophical Transactions, 1840 and 1841.

Barry they are considered as resulting from a transformation of the ordinary red corpuscles, such as occurs when they are about to resolve themselves into solid tissues, or into pus-globules. Not having studied the chyle-globules, however, he does not offer any opinion regarding their identity with these (§ 597). It has been observed by Mr. Gulliver and others, that in inflammatory states of the system, the colourless globules are much more abundant in the blood than in health; and that they are especially numerous in suppurative diseases. The white globules, described by M. Mandl, are probably altogether different; being formed by the simple coagulation of the fibrin, and having no proper structure. (See latter part of § 589).*

[The continuation {of the nutritive process by the elaboration of organizable plasma} has been regarded by Wagner, Henle, and Wharton Jones, as one of the functions (probably the chief one) of the *red* corpuscles. To this view, however, there are certain objections, which appear to the author to be of a very decided character. In the first place, there is no constant proportion between the amount of fibrin in the blood, and the number of its red corpuscles. The researches of Andral have clearly shown, that in the inflammatory condition of the blood there is a decided increase, often a most astonishing one, in the amount of the fibrin; whilst there is no corresponding augmentation in the number of red corpuscles. Indeed, this augmentation is not incompatible with a chlorotic state of the blood; the peculiar characteristic of which is a great diminution in the amount of red corpuscles. Again, in fever, the characteristic alteration in the condition of the blood appears to be an increase in the amount of red corpuscles, with a diminution in the quantity of fibrin; yet if a local inflammation should establish itself during the course of a fever, the proportion of fibrin will rise, and this without any change in the amount of corpuscles. By such alterations, the normal proportion between the quantity of fibrin and corpuscles, which may be stated as $a : b$, may be so much altered as to become $4a : b$, or $a : 4b$. Can it be supposed, then, that the elaboration of the fibrin is a consequence of the action of the red corpuscles? Another important fact,

* The white or colourless globules mentioned in this paragraph have been recently examined minutely by Dr. Barry and by Remak. These excellent observers agree in regarding them as cells, within which other cells are being produced; and both assert, that the new or secondary cells thus formed, in the circulating blood, are nothing else than blood-discs. Both, also, have applied to these globules the term "parent-cells." Although ordinarily spoken of as white or colourless, these globules are not in reality at all times free from colour; for, when the young blood-discs they contain are nearly mature, *their* colour can be readily distinguished through the parietes of the parent-cell. The statement in the text in regard to the increased number of such globules contained in the blood in inflammatory states of the system, acquires new value from the observation of Remak, that the buffy coat of the blood is not unfrequently made up of them. Thus we learn that in Inflammation there is an increased energy in the formative processes, as manifested not only in the augmented amount of fibrin, but in the unusual tendency to reproduction of the blood-corpuscles. In regard to the origin of the parent-cells, Dr. Barry states it as his opinion, founded upon extensive and careful observation, that they are nothing else than transformed blood-corpuscles, which thus multiply one another; and in regard to their ultimate purpose, it is the opinion of the same observer, that the young cells they contain may enter at once into the composition of newly-forming tissues, the history of the first development of which is given by him with great minuteness. He further considers that they are identical with the exudation-corpuscles previously mentioned. Thus they are the parent-cells, not only of the blood-discs, but of the cells of all the solid tissues. (See Dr. Barry's Supplementary Note to his Third Series of Researches on the Blood-Corpuscles, in the Philosophical Magazine for Oct. 1841; and Remak in Medicinische Zeitung, Juli, 1841, and Brit. and Foreign Medical Review, Jan. 1842.)

having the same bearing, has been ascertained by Remak. He found that, when an animal is bled largely and repeatedly, the quantity of red corpuscles in its blood is greatly diminished, whilst the proportion of the colourless corpuscles is increased; now, as it has been ascertained by Andral's investigations that the quantity of fibrin is but little affected by bleeding, it would seem that the white rather than the red corpuscles are the agents of its elaboration.

Again, there appears to be a total absence in the blood (?) of invertebrated animals of any red corpuscles* resembling those of the blood of Vertebrata; yet in this fluid the elaboration of albumen into fibrin must be taking place, for the nutrition of the tissues, as in the higher animals. It is true that their nutritious fluid contains globules; but these globules bear a much stronger resemblance to the corpuscles of the chyle, or to the colourless corpuscles of the blood, than they do to the red corpuscles of the Vertebrata. So well marked is this resemblance, that, as Wagner† himself has suggested, the circulating fluid of the Invertebrata is to be considered as rather analogous to the chyle than to the blood of vertebrated animals,—a doctrine which appears to the author extremely probable.

These two objections seem of themselves sufficient, in the absence of any affirmative evidence, to overthrow the hypothesis that the elaboration of fibrin is the act of the *red* corpuscles. But there is another class of blood-particles, to which increased attention has recently been directed, and in regard to whose function the very same evidence with that just produced weighs strongly in the affirmative. These are the *colourless* corpuscles or *lymph*-globules. The former term I prefer, as expressing their distinctive appearance; the latter involves the supposition that they are identical with the corpuscles of chyle and lymph, which cannot be regarded as yet demonstrated, though it appears to me highly probable. There is a remarkable uniformity in the size and appearance of these in all vertebrate animals, notwithstanding the immense difference in the size of the red corpuscles. The colourless corpuscles have not yet been observed to vary much from the diameter of 1-3000th of an inch; whilst the red corpuscles vary from less than 1-12,000th (musk-deer) to 1-337th (Proteus) of an inch. Moreover, in very young embryos of Vertebrata (as I learn from Mr. Gulliver) the white globules are nearly as numerous as the red particles. This Mr. Gulliver has often seen in fœtal deer, about an inch and a half long. In a still smaller fœtus the blood was pale from the preponderance of the white globules; and in such embryos the coloured corpuscles have a very distinct pale globular nucleus. It is therefore a fact of much interest, that, even in the mammiferous embryo, at the period when growth is most rapid, the blood has a strong analogy to that of the Invertebrata. It is then, too, most analogous to chyle; since it consists of the fluid elaborated from the organizable matter supplied by the parent, and directly introduced into the current of the circulation. The function of the placenta is double; for it is at the same time the medium of introducing into the circulating fluid of the fœtus the alimentary materials supplied by the parent; and of aerating the fluid which has traversed the fœtal system. It is not until the lungs and digestive apparatus of the embryo have commenced their independent operation, that the distinction between its blood and its chyle becomes manifest. We should expect to find in the blood of the fœtus, therefore, up to the

* The red-blooded annelida do not form an exception to this rule. The colouring principle of their circulating fluid exists in its *plasma*, not in globules.
† Physiology, translated by Willis, p. 278, et. seq.

time of birth, a large proportion of white corpuscles; and this circumstance has been noticed by Dr. Barry (and communicated to me by him) with regard to the blood of the umbilical vessels of a placenta which he had the opportunity of examining very shortly after its expulsion. The fact was regarded by Dr. Barry as indicating that the production of the colourless corpuscles of the blood is independent of the chyle-globules; but I am disposed to interpret it in exactly the opposite manner; since, as I have shown, the placental blood has considerable analogy to the circulating fluid of the Invertebrata, which have no lacteals, and may be considered, therefore, as partly representing the chyle of the adult vertebrated animal. The colourless corpuscles are the kind of globules *most universally present* in the circulating fluid; for whilst the red particles are confined to Vertebrata, the former are found in the circulating fluid of all animals, even where there are no distinct vessels.

A very interesting observation has recently been published by Mr. Addison, (Prov. Med. and Surg. Journ. Aug. 20, 1842,) which appears to the author to throw great light on the much-disputed question of the digestive apparatus of the polygastric animalcules. The numerous globular particles generally to be seen in their transparent bodies, but becoming more numerous and distinct when the animalcules have been recently feeding, are regarded by Ehrenberg as stomachs, opening out of an intestinal tube. This account of them has been objected to by other observers, on the ground, that these particles are seen to undergo a regular movement, as if they were floating in the midst of a fluid filling the general interior cavity of the body, and that they are sometimes discharged through the anal orifice. Of the validity of this objection, the author's own observations have satisfied him. It is stated by Mr. Addison that, when a polygastric animalcule is touched by liquor potassæ, its body bursts, and liberates the so-called stomachs, which are evidently destitute of any structural connection with it; these corpuscles, when they come under the influence of the same reagent, themselves swell and burst, discharging a number of minute granules; and thus undergoing precisely the same change as that which is effected in the colourless corpuscles of the blood by the alkaline fluid. I cannot doubt that these particles are cells which float in the fluid of the ody, and elaborate the materials for its nutrition, in the same manner as do those of the chyle and blood of higher animals.

The presence of colourless corpuscles, sometimes to a large amount, in the blood of reptiles, has long been known; since their rounded form and comparatively small size enables them at once to be distinguished from the large oval nucleated red corpuscles of these animals. They bear so strong a resemblance in mammalia, however, to the red corpuscles of the blood, both in size and figure, that their existence, at least to any similar amount, has not been generally recognized. There can be no doubt, however, that they perform as important a function in the blood of Mammalia as in that of Reptiles; and several facts of the same kind, which have been recently observed, seem to indicate the nature of this function with much probability. It has been (in my opinion at least) satisfactorily ascertained by the observations of Mr. Gulliver, (Philos. Mag. Sept. 1838,) and others, that the usual amount of colourless corpuscles in the blood is very much increased at the time when an increase of fibrin is taking place,—that is, in the inflammatory condition; and according to the observations of Remak, Barry, and Addison, the buffy coat usually contains a large number of them. Their increase appears to have some relation with the local inflammatory change; for they are particularly abundant in the blood of inflamed parts, as noticed

by Mr. Addison in that drawn by the prick of a needle from a pimple, the base of a boil, the skin in scarlatina, &c.; and they may be seen to accumulate in the vessels of the frog's foot, on the application of stimuli to the part. A corresponding multiplication of the colourless corpuscles takes place in several other instances, in which the formative processes are peculiarly active, and in which the demand for fibrin must therefore be greatly increased. Thus the buffy coat of the blood of pregnant women contains a very large number of them. It is stated by Wagner, (Op. cit. p. 245,) that the number of colourless corpuscles is always remarkably great in the blood of well-fed frogs just caught in the summer season; and that it is very small in those that had been kept long without food, and in those examined during the winter. Their large proportion in the embryo, and gradual decrease as the formative processes become less active, has been already noticed.

The very facts, therefore, which tend to prove that the *red* corpuscles do not perform the elaboration of the organizable plasma, are equally cogent in favour of the doctrine that this function is to be attributed to the white or *colourless* corpuscles; and this view is borne out by other facts, which indicate that there is a decided relation between the *colourless* corpuscles and the *nutritive* or organic life of the tissues; and a corresponding relation between the *red* corpuscles and their *functional activity*. All observers who have studied the capillary circulation with attention, agree in the statement, that there is a marked difference in the movements of the two classes of corpuscles; the white corpuscles rolling slowly along in the almost motionless layer of plasma which lines the capillaries, whilst the red particles are carried briskly onwards in the centre of the stream. It is difficult to avoid the inference that (to use the words of Mr. Wharton Jones) "there is some reciprocal relation between the colourless corpuscles and the parts outside the vessels, in the process of nutrition." On the other hand, that the presence of the red particles has an important influence in maintaining the excitability of organs, especially the nervous and muscular systems, has long ranked as a physiological truth; and it is fully explained on the principles which Liebig has propounded, with reference to the necessity for oxygen in the active vital operations of the tissues, and the share taken by the red corpuscles in carrying it through the system. It is unnecessary to do more than state here, that Liebig regards a certain disintegration of the tissue as the means of manifesting its vital force, or peculiar property; for this disintegration, the presence of oxygen is requisite; and the oxygen taken in at the lungs is carried through the system chiefly (but not entirely) by the red particles of the blood entering into a chemical combination with their protoxide of iron, which gives place in the systemic capillaries to another,—the oxygen being there set free, and replaced by carbonic acid, which is again exchanged for oxygen in the lungs. That the proportion of red corpuscles in the blood bears a distinct relation to the nervous and muscular energy of the animal, and to the amount of oxygen consumed by it, has long ranked as a physiological fact. An exception might be pointed out in regard to insects, which have no red corpuscles, and yet can display a greater amount of animal energy, and may consume a larger quantity of oxygen in proportion to their size, than beings of any other class whatever. But here, as elsewhere, *exceptio probat regulam*; for the conveyance of oxygen through the tissues is not in them accomplished by the circulating fluid, which has a comparatively sluggish movement, but is effected more directly by the ramifying tracheæ which introduce air into the minutest portions of the structure.]—C.

580. Besides the red corpuscles and the colourless globules, it is stated by Mr. Gulliver,* that the blood obtained from Mammals after death not unfrequently contains an abundance of white matter, generally presenting the form of spherules, having a diameter of from 1-4000th to 1-1750th of an inch. They frequently seem to have a semifluid consistency, especially in the blood of the mesenteric veins, in which the white matter is found most abundantly. The appearance of these globules is probably to be attributed to pathological changes, and especially to the existence of tubercular disease; a large proportion of the granular matter of caseous tubercles consists of similar corpuscles.—The milky serum which sometimes occurs when patients are bled not long after a meal, and which is seen not unfrequently in the blood drawn from young animals, is usually found, by the highest powers of the microscope, to present the granular base, which has been already described in the account of chyle (§ 563). The appearance seems due, however, in some instances, to the diffusion of oily matter, in a less finely divided state than usual, through the fluid; in some of these cases, a very large amount of fat has been shown, by chemical analysis, to exist in it.—The only visible constituents of ordinary blood which remain to be noticed, are the corpuscles of the Spleen (§ 708) and of the Supra-renal capsules (§ 711) which may be frequently observed in the Splenic and Supra-renal veins respectively.—According to Schultz, the red corpuscles of the portal vein differ from those of the rest of the vascular system in their tendency to decay; their colouring matter is soluble in the liquor sanguinis, which is not the case elsewhere; and they seem to have lost a portion of their contractility.

581. Having now separately considered the chief organic elements which enter into the composition of the Blood, we are prepared to inquire into the characters of this fluid as a whole. The analysis which has been recently made by M. Lecanu† is usually regarded as the most complete and satisfactory. The following is his account of the composition of the fluid obtained from two stout and healthy men.

Water	780·145	785·590
Fibrin	2·100	3·565
Albumen	65·090	69·415
Colouring matter (globules)	133·000	119·626
Fatty crystallizable matter	2.430	4.300
Oily matter	1·310	2·270
Extractive matter soluble in water and alcohol	1·790	1·920
Albumen combined with soda	1·265	2·010
Chloride of sodium; ——— potassium; Carbonates, Phosphates, Sulphates of potash and soda	8·370	7·304
Carbonates of lime and magnesia; Phosphates of lime, magnesia, and iron; Peroxide of iron	2·100	1.414
Loss	2·400	2·586
	100·000	100.000

* Gerber's Anatomy, Appendix, p. 21.
† Journal de Pharmacie, Nos. ix. and x., 1831.

Hence it is seen that the proportion of the elements of Blood is subject to considerable variation within the limits of ordinary health; we shall hereafter find that, in disease, these variations are far more decided, and that they have a constant and evident connection with the morbid condition of the system. The amount of solid matter in the blood appears to be in general greater in the male than in the female. The following table exhibits the general results of the inquiries of Denis on this head: it represents the maximum and minimum of each of the chief constituents of the blood; and it will be seen that, whilst the water predominates in the female, the other elements (with a slight exception in favour of the albumen) are in largest amount in the male.

	Male.		Female.	
	Maximum.	Minimum.	Maximum.	Minimum.
Water . .	805	732	848	753
Albumen . .	63	48·5	68	50
Globules . .	186	110·5	167	71·4
Fibrin . .	4	2	3·1	2

The Specific Gravity of course varies with the amount of solid matter contained in it; in the Human subject, the average is probably about 1050. The estimate formerly given (§ 490) of the proportional amount of blood in the body has recently been confirmed by a very ingenious experiment of Valentin's, in which the calculation was based on the specific gravity. A certain quantity of blood was taken away from the jugular vein of an animal of known weight; and a known measure of blood-warm distilled water was slowly injected, by the orifice of the vein, towards the heart. Some minutes afterwards, another portion of the blood was withdrawn and carefully weighed. The two quantities were then evaporated in dry air, until the residue no longer lost weight; and the whole amount of the previously-contained mass of blood could then be calculated, by a simple mathematical formula, from the degree of attenuation in the fluid, produced by the injected water. This was found to be between one-third and one-fourth, or about two-sevenths of the whole weight of the body.

582. When the blood is drawn from the body and left to itself, its organic elements speedily undergo a new arrangement. The fibrin coagulates, and separates itself from the fluid in which it was previously dissolved; and during its coagulation it attracts the red particles; these are included in areolæ or meshes of the clot, the substance of which has a tendency to assume a fibrous arrangement (§ 554); and they usually group themselves together in columnar masses, resembling piles of money (Fig. 53, B). The coagulum or clot becomes dense in proportion to the amount of the fibrin it contains; and the albuminous and saline matter still dissolved in the water are separated from it, constituting what is called the serum. This separation will not occur, however, if the coagulation take place in a shallow vessel; nor if the amount of fibrin should be small, or its vitality low. A homogeneous mass, deficient in firmness, presents itself under such circumstances; though the solid part of this may pass into a state of more complete condensation after the lapse of a certain time. That the coagulation is due to the fibrin, and that the red particles are merely passive in the process, appears from several considerations. A microscopical examination of the clot shows that it has the same texture with fibrin when coagulating by itself; the globules clustering together in

the interspaces, and not being uniformly diffused through the mass. Their specific gravity being greater than that of the fibrin, they are usually most abundant at the lower part of the clot; and the upper surface is sometimes nearly colourless, especially when the coagulation has taken place slowly; yet this upper part is much firmer than the under, showing that the fibrin alone is the consolidating agent. This has been proved to demonstration by an experiment of Müller's. He placed the blood of a Frog, diluted with water (or still better with a very thin syrup) on a paper filter, of sufficiently fine texture to keep back the corpuscles (§ 574); and the liquor sanguinis, having passed through the filter completely unmixed with globules, presented a distinct coagulum, although, from the diluted state of the fluid, this did not possess much consistency. Owing to the more minute size of the blood-discs of warm-blooded animals, this experiment cannot be performed with their blood; but there is no reason to believe its constitution to be different. In fact, the sole agency of the fibrin in coagulation is very easily proved in another way. If fresh-drawn blood be continually stirred with a stick, the fibrin will adhere to it in strings during its coagulation; and the red particles will be left suspended in the serum, without the slightest tendency to coagulate. Moreover, if a solution of any salt that has the property of retarding the coagulation (such as carbonate of potash or sulphate of soda) be added to the blood, the corpuscles will have time to sink to the lower stratum of the fluid before the clot is formed; the greater part of the coagulum is then entirely colourless, and is found by the microscope to contain few or no red particles.

583. That the coagulation of the Fibrin is not, as some have supposed, a proof of the death of the blood, but is rather an act of vitality, appears evident from what has been already stated (§ 554) of the incipient organization which may be detected even in an ordinary clot; and still more from the fact that, if the effusion of fibrin take place upon a living surface, its coagulation is the first act of its conversion into solid tissues possessing a high degree of vitality. It is absurd to suppose that the blood dies, in order to assume a higher form. When withdrawn from the body, however, the coagulation of the blood is the last act of its life; for, if not within the influence of a living surface, it soon passes into decomposition. Instances occasionally present themselves in which the blood does not coagulate after death; and in most of these there has been some sudden and violent shock to the nervous system, which has destroyed the vitality of solids and fluids alike. This is generally the case in men and animals killed by lightning or by strong electric shocks; and in those poisoned by prussic acid, or whose life has been destroyed by a blow on the epigastrium. It has also been observed in some instances of rupture of the heart or of a large aneurism near it; and a very interesting phenomenon then not unfrequently presents itself,—the coagulation of the blood which has been effused into the pericardium (the effusion having taken place during the last moments of life), whilst that in the vessels has remained fluid. In several instances in which the blood has been found uncoagulated in the vessels, many hours after death, a portion withdrawn from the body has clotted; this would seem to indicate that there is some absolutely depressing influence exercised by the surrounding tissues under such circumstances,—an influence of which manifest evidence is afforded by the sudden destruction of the muscular contractility, the arrestment of the capillary circulation, and other phenomena of like nature. It appears, however, that simple arrestment of nervous influence favours the coagulation of the blood in the vessels; clots being found in their trunks

within a few minutes after the brain and spinal marrow have been broken down.

584. The length of time which elapses before coagulation, and the degree in which the clot solidifies, vary considerably; in general, they are in the inverse proportion to each other. Thus, if a large quantity of blood be withdrawn from the vessels of an animal at the same time, or within short intervals, the portions that last flow coagulate much more rapidly, but much less firmly, than those first obtained. In blood drawn during inflammatory states, again, the coagulation is usually slow, but the clot is preternaturally firm, especially at its upper parts, where the buffy coat (§ 588) or colourless stratum of fibrin gradually contracts, and produces the *cup* which is usually regarded as indicative of a high degree of inflammation. Except under the peculiar circumstances just stated, the blood withdrawn from the body always coagulates,* whether it be kept at rest or in motion, whether its temperature be high or low, and whether it be excluded from the air or admitted to free contact with the atmosphere. The coagulation may be accelerated or retarded, however, by variation in these conditions. Thus, if the blood be continually agitated in a bottle, its coagulation is delayed, though it will at last take place in shreds or insulated portions; but that rest is not the cause of its coagulation (as some have supposed), is proved by the fact that, if a portion of blood be included between two ligatures in a living vessel, it will remain fluid for a long time. Again, the coagulation is accelerated by moderate heat, and retarded by cold; but it is not prevented even by extreme cold, for, if blood be frozen immediately that it is drawn, it will coagulate on being thawed. Moreover it is accelerated by exposure to air, but it is not prevented by complete exclusion from it, as is proved by its taking place in vacuo, or in a shut sac within the dead body: complete exclusion from the air, however, retards the change; as has been shown by causing the blood to flow into a vessel containing oil, which will form an impervious coating on its surface, and will occasion the coagulation to take place so slowly, that the red particles have time to subside, and the upper stratum of the clot is colourless.† An extrication of carbonic acid usually takes place to a slight degree during coagulation; but this is not a constant occurrence; and the process is not prevented even by agitating carbonic acid with the blood.

585. The proportions of Serum and Clot which present themselves after coagulation are liable to great variation, independently of the amount of the several ingredients characteristic of each; for the coagulum may include not only the fibrin and red particles, but also a large proportion of the serum, entangled as it were in its substance. This is particularly the case when the coagulation is rapid; and the clot then expels little or none of it by subsequent contraction. On the other hand, if the coagulation be slow, the particles of fibrin seem to become more completely aggregated, the coagulum is denser at first, and its density is greatly increased by subsequent contraction. When a firm fresh clot is removed from the fluid in which it is immersed, its concretion is found to continue for 24 or even 48 hours, serum being squeezed out in drops upon its surface; and in order, therefore, to form a proper estimate of the relative proportions of crassamentum and serum, the former should be cut into slices, and laid upon

* Some diseases may perhaps be an exception; non-coagulation of the blood is said to be characteristic of Scurvy, but this is erroneous. In very severe forms of Typhus, the same has been stated to occur.

† Babington in Medico-Chirurgical Transactions, Vol. xvi.

bibulous paper, that the latter may be pressed from it as completely as possible. According to the experiments of Mr. Thackrah, coagulation takes place sooner in metallic vessels than in those of glass or earthenware, and the quantity of serum separated is much less; in one instance, the proportion of serum to clot was as 10 to 24½, when the blood coagulated in a glass vessel; whilst a portion of the same blood coagulating in a pewter vessel gave only 10 of serum to 175 of clot. The specific gravity of blood is no measure of its coagulating power; for a high specific gravity may be due to an excess in the amount of globules, which form the heaviest part of the blood; and may be accompanied by a diminution in the quantity of fibrin, which is the coagulating element.

586. The Serum, when completely separated from the crassamentum, may be said to contain all the Albumen and saline matter of the blood, together with a portion of the fatty matter (of which some adheres to the fibrin), and those "ill defined animal principles" which are included under the designation "extractive matter." Its specific gravity may be stated at about 1030 in health; and it contains about 9½ per cent. of solid matter. When it is heated to 160°, its albumen coagulates, and the remaining fluid may be separated by pressure. This fluid still contains some albumen, which is held in solution by free alkali; for if the latter be neutralized by acetic acid, a further precipitation takes place on the application of heat. The fatty matter, which may be separated by ether, seems to be nearly allied to the several fatty substances formed in the body; for some chemists have determined it to consist of oleine, margarine, and stearine, the constituents of ordinary fat; whilst others regard it as analogous to cerebrine, the fatty matter of the brain; and others, again, consider it to bear a closer resemblance to cholesterine, the fatty matter of the bile. The extractive matter partly consists of lactic acid, partly of a substance called osmazome; it is believed by Berzelius that this portion of the blood contains the resultants of the acts of decomposition continually taking place in the body; and that it is chiefly, therefore, from this that the excretions are formed.

587. It cannot be doubted that, upon the due admixture in the Blood of all these elements, the regular performance of its actions is dependent. In regard to its physical properties merely, it is easily shown that a slight alteration may produce the most injurious consequences; for a certain degree of viscidity has been found (by the experiments of Poisseuille) to favour the passage of fluid through capillary tubes; and thus, if the viscidity of the blood be diminished by a loss of part of its Fibrin, stagnation of the current, and extravasation of a portion of the contents of the vessels, will be the result. This has been fully proved by the numerous experiments of Magendie, and the fact is one of very important pathological applications (§ 593). In regard to the effect of alterations in the amount of the Red Particles, our information is less satisfactory, since it is almost impossible to deprive blood of these, without at the same time defibrinizing it. It appears, however, from the experiments of Dieffenbach on transfusion, that they are more effectual as stimuli to the heart's action, than is any other constituent of the blood; and, if the hypothetical account of their use already offered (§ 578) have any correctness, they must be important agents in the maintenance of the capillary circulation also. The rapidity with which they may be decomposed and reconstituted, is made remarkably evident by the experiments of Magendie; who found that, when the blood of one animal was injected into the veins of another having discs of very different size and form (care being taken to prevent the coagulation of the fibrin during the operation), the original red particles soon disappeared,

and were replaced by those characteristic of the species in whose veins the fluid was circulating. The Albumen of the blood seems to be of importance chiefly as being the material from which Fibrin is elaborated. It is at present uncertain how far it is deposited in the tissues without undergoing that alteration; for the results of the Chemical Analysis of these leave it quite uncertain whether the element usually designated as coagulated albumen, is not in reality fibrin, and even if the former should exist in the semi-organic deposits which enter into the composition of some of the animal solids, the latter is probably the ingredient at the expense of which all the fully-organized structures are formed, and not muscular fibre alone, as was once supposed. The continual drain upon the Fibrin, which is taking place in the capillaries of the system, is made evident by the remarkable fact that arterial blood contains a much larger proportion of it than venous,—the excess being usually about one-fifth.

588. The crassamentum not unfrequently exhibits, in certain disordered conditions of the blood, a layer of fibrin nearly free from colour; and this is known as the *buffy coat*. The presence of this has been frequently regarded as a sign of the existence of inflammation, occasioning an undue predominance of fibrin; but this idea is far from being correct, since, as will presently appear (§ 589), it may result from a very opposite condition of the blood. A similar colourless layer of fibrin is always observable, when the coagulation of the blood is retarded by the addition of agents that have the power of delaying it (§ 582;) and since, in inflammatory states of the system, the blood is generally long in coagulating, it has been supposed that the separation of the red particles is due to this cause alone. Dr. Alison,* however, maintains that there must be an absolute tendency to separation between the two components of the clot, in order to account for the phenomena sometimes presented by it; and he adduces the two following reasons in support of this view. "1. The formation of the buffy coat, though no doubt favoured or rendered more complete by slow coagulation, is often observed in cases where the coagulation is more rapid than usual; and the colouring matter is usually observed to retire from the surface of the fluid in such cases, before any coagulation has commenced. 2. The separation of the fibrin from the colouring matter in such cases, takes place in films of blood so thin as not to admit of a stratum of the one being laid above the other; they separate from each other laterally, and the films acquire a speckled or mottled appearance, equally characteristic of the state of the blood with the buffy coat itself." Whether this tendency is due to an increased attraction among the particles of each, or to a peculiar repulsion between the two, is doubtful; the former, however, would seem the most probable, since it is in the case of buffy blood that the firmest concretion of the clot, owing to the tenacity and slow coagulation of its fibrinous element, is observed.

{That the formation of the *buffy coat* is due to an increased attraction of the red corpuscles for each other, would seem to be proved by the observations of Professors Nasse, Wagner, Henle, and Mr. Wharton Jones. On examining a drop of newly drawn healthy blood under the microscope, you will observe, if the blood be spread out on a thin plate of glass, that the corpuscles are uniformly diffused through the liquor sanguinis. In the course of half a minute there is a tendency to aggregation exhibited; the corpuscles approach one another, overlap, and become applied side by side, and the columnar arrangement (fig. 53) occurs. The intervening spaces contain

* Outlines of Physiology, 3rd edit. p. 83.

only liquor sanguinis, with an occasional red or colourless corpuscle. The white and red corpuscles remain perfectly distinct, not the slightest attraction being exhibited between them. After one or two minutes a heaving among the rolls takes place by which they are broken, and the corpuscles become more or less detached. This natural appearance is seen only when the drop of blood is thinly spread out. If a coagulated drop be examined, the rolls of red corpuscles are disposed so as to form a sponge-work, the liquor sanguinis being contained in the interstices. Were the nature of the force which effects this mutual approach and aggregation of the corpuscles, solely a mere repulsion between the liquor sanguinis and red corpuscles, similar to that which exists between oily fluids and moist substances, would not the aggregation of the corpuscles be irregular, instead of the definite arrangement which invariably is seen, and would any subsequent separation and dispersion of the blood discs occur? Is there not besides this want of attraction between the red corpuscles and the liquor sanguinis, a special attraction of the former for one another,—an exaggeration in the natural disposition of the red corpuscles to run together? We have then in that state of the blood which gives rise to the buffy coat, besides a relatively greater amount of liquor sanguinis, with its increased proportion of fibrin, &c., a notable diminution in the red corpuscles,* which are thinner, more pliable, and frequently viscid on the surface, and evince an exaltation in their normal tendency to aggregate in rolls. A sponge-work is ultimately formed, which, squeezing out the liquor sanguinis from among the corpuscles, permits the greater specific gravity of the blood discs to operate, whereby the liquor sanguinis collects on the surface, and, coagulating, forms the buffy coat. By a practical knowledge of this process, and by bearing in mind the mottled, speckled appearance described above of a thin film of blood, in which the buffy coat is to form, the microscopic examination of a single drop of blood, drawn from the finger, will afford us all the information that we may require on the state of the blood.—See Wharton Jones's Observations on the Blood. Brit. & For. Med. Rev., Vol. XIV.—M. C.}

589. The essential condition of the formation of the buffy coat is an increase in the quantity of fibrin in proportion to the globules, and not a simple increase of fibrin. When the blood contains an excessive quantity of fibrin, it coagulates slowly; thus the blood of a patient labouring under rheumatism coagulates more slowly than that of one affected with typhoid fever. The increase may occur in two ways;—either by an absolute increase in the fibrin, the amount of the globules remaining unchanged, or not being augmented in the same proportion;—or by a diminution of the globules, the quantity of fibrin remaining the same, or not diminishing in the same proportion. Hence in severe chlorosis, in which the latter condition is strongly developed, the buffy coat may be as well marked as in the severest inflammation. Unless the composition of the blood be altered in one of these two ways, it is stated by Andral that the buffy coat is never formed; the influence of circumstances which favour it being not sufficient to produce it when acting alone. The absence of these circumstances may

{* That there is an increase in the number of the colourless corpuscles in buffed blood cannot be denied, but that it takes place to any great amount seems doubtful; and the supposition of Mr. Addison and Dr. Barry, that their rising to the top, and subsequent coalescence forms the buffy coat, is entirely inaccurate. An examination of the coagulated fibrin of the buffy coat under the microscope, shows the lymph-globules interspersed through the fibres and granules of the solidified fibrin as nucleated corpuscles.—M. C.}

prevent it, however, when it would otherwise have been formed; thus, when the blood flows slowly, the buff is not properly produced, because the slow discharge gives one portion time to coagulate before another, and only the blood last drawn furnishes the fibrin at the upper part of the vessel. Again, in a deep narrow vessel, the buff will form much more decidedly than in a broad shallow one; because the thickness of the fibrinous crust will be greater. If the blood be agitated during its coagulation, the globules are mixed up with the fibrin; and the crust is imperfect and soft. The process of the formation of the buffy coat may be best studied by treating ordinary blood with some of those agents which retard its coagulation. Of these, the sulphate of soda is stated by Andral to be the best, producing no alteration in the character of the elements, but simply delaying their change of state; and the following is his account of the appearanees observed. After a few minutes the blood separates into two parts; the lower one contains the globules collected together into a soft mass; the upper one is at first transparent and resembles serum, but soon becomes opaque. At this period, a number of globular white corpuscles may be seen in it with the microscope; and these form the first degree of solidification of the fibrin. After 48 hours, the fluid contains numerous flocci like spider-webs, which flocci are found to be composed of globular corpuscles beginning to coalesce; this is the second stage of solidification. After 96 hours, the fluid recovers its transparency and contains no trace of separate corpuscles; but the flocci are more numerous, more firm, and constitute an irregular web, composed of fibres arranged in various directions. Where the web is thickest, several reticulated layers may be seen, the one placed over the other; and in the midst of the distinct fibres, several strings of corpuscles still retaining their globular character, are perceived. This state of organization is intermediate between that in which the corpuscles are altogether separate, and that in which a firm coagulation of the fibrin takes place; and it may be seen to be that through which the buffy coat passes in the progress of its formation.

Pathological Changes in the Blood.

590. From the part which the Blood performs in the ordinary processes of Nutrition, it cannot be doubted that it undergoes important alterations when these processes take place in an abnormal manner. These alterations must be sometimes the causes, and sometimes the effects, of the morbid phenomena which constitute what we term the disease. Thus, when some local cause, affecting the solid tissues of a certain part of the body, produces inflammation in them, their normal relation to the blood is altered; the consequence is, that the blood, in passing through them, undergoes a different set of changes from those for which it is originally adapted; and thus its own character undergoes change, which soon becomes evident throughout the whole mass of the circulating fluid, and is, in its turn, the cause of morbid phenomena in remote parts of the system. On the other hand, the strong analogy between many constitutional diseases, and the effects of poisonous agents introduced into the blood, appears clearly to point to the inference, that these diseases are due to the action of some morbific matter, which has been directly introduced into the current of the circulating fluid, and which has affected both its physical and its vital properties.* Here, then, is a wide field for investigation, of which the surface

* This doctrine has been recently brought prominently forwards in a Paper on Symmetrical Diseases, read by Dr. William Budd before the Medico-Chirurgical

can scarcely be said to be yet broken up, and which must yield an abundant harvest to those who shall cultivate it with intelligence and zeal. The only connected reseaches which have been yet made, on the changes which the blood undergoes in disease, are those of MM. Andral and Gavarret;* and these are confined to the alterations which take place in the proportions of the organic elements of the fluid. It is of course necessary to determine, in the first instance, what are the usual or normal proportions; and the following is estimated by them, from numerous analyses, as the ordinary quantity† of each element in 1000 parts of healthy blood. The proportion of fibrin may probably vary,

Fibrin	3
Globules	127
Solid matter of serum	80
Water	790

within the limits of health, from 2½ to 3½ parts in a thousand.

591. The inquiries which have been made by Andral, in regard to the alterations which these proportions undergo in various states of disease, have already led to results of great interest and value: and there can be no doubt that these will be greatly extended, when this simple analytical process shall have been more generally employed. As an instance of the erroneous conclusions into which we may be led, by merely attending to the size of the crassamentum, it may be remarked that the existence of a large clot does not by any means necessarily imply the presence of an increased amount of fibrin; since it may depend upon the retention within it of a large proportion of serum, consequent upon the deficient contractile power of the

Society, Dec. 16, 1841. The Author ingeniously proves that the symmetry of many diseases (such as certain forms of cutaneous eruptions, rheumatism, &c.) which do not immediately depend upon external causes, necessarily involves the idea of the conveyance of the morbific agent in the circulating fluid; the palsy produced by lead is a very interesting example, in which the agent is known to be mingled with the blood, and to be deposited in the parts affected, which are generally, if not always, symmetrical.

* An account of these inquiries will be found in the Provincial Medical and Surgical Journal for May, June, and July, 1841; in the Annales des Sciences Naturelles, Dec. 1840, and March 1841; in the Ann. de Chimie, {and in the Medical Examiner, Vol. III.}

† The analysis of the Blood with reference to the quantity of the chief proximate elements which it may contain, is very easily accomplished; and as the determination of this is the point of most practical importance, the method adopted in the inquiries of MM. Andral and Gavarret will be here detailed. The blood is caused to flow into two different vessels; into one vessel, the first and last quarters of the blood are received; and into the other, the second and third quarters: in this manner, the similarity of the two quantities is secured as far as possible. The blood in one vessel is allowed to coagulate spontaneously; that in the other is beaten with a small rod, in order to separate the fibrin. When the first portion has completely coagulated, the serum is carefully separated from the crassamentum; and there are then dried and weighed,—1. The fibrin obtained by the rod;—2. The whole crassamentum;—3. The serum. The weight of the separated fibrin gives us the quantity of it contained in the clot. The weight of the serum after complete desiccation gives us the proportional quantity of solid matter contained in its water. The quantity of water driven off from the clot in drying, gives us the amount of serum it contained; from which may be estimated the proportion of the solid matter of the serum that the crassamentum contained. Hence, by deducting from the weight of the whole dried clot, first, that of the fibrin separated by agitation, and then that of the solid elements of the serum, ascertained by calculation, we obtain the weight of the globules. In order to ascertain the whole amount of solid matter in the serum, that which was ascertained by calculation to exist in the fibrin is added to that which was obtained from the separate serum. The proportion of organic and of inorganic matter in this solid residuum is ascertained by incinerating it in a crucible; by which the whole of the former will be driven off, and the latter will be left.

clot that results from a diminution in the proportion of fibrin. When the clot is dense and contains but little serum, it may be judged to contain a full proportion of fibrin, even though it may itself be small. Before entering upon the consideration of the alterations in the blood which are effected by particular morbid states, Andral notices two extraneous causes, usually operating in disease, which may affect the result. These are, abstinence from food, and loss of blood by venesection. It has been commonly stated that they have a tendency to diminish the proportion of all the solid elements of the blood; but this is not the case; for they seem especially to act upon the globules, the quantity of fibrin remaining nearly the same,—unless the hemorrhage have been very severe, in which case the fibrin and the solid matter of the serum are also reduced in amount. The extreme variations of each ingredient noticed by Andral were,—fibrin, from 0·9 to 10·0 in every 1000 parts of blood; the globules, from 21 to 185; the solid parts of the serum, from 57 to 104; and the water from 725 to 915. The smallest proportion of globules and the largest amount of water were presented in a case of severe uterine hemorrhage.

592. The most important fact substantiated by Andral is one that had been previously suspected,—the invariable increase in the quantity of fibrin during acute inflammatory affections; the increase being strictly proportional to the intensity of the inflammation, and the degree of symptomatic fever accompanying it. "The augmentation of the quantity of fibrin is so certain a sign of inflammation, that, if we find more than 5 parts of fibrin in 1000, in the course of any disease, we may positively affirm that some local inflammation exists." Several cases are mentioned, in which an increase to 7 or 7½ parts took place without any apparent cause; but in which it afterwards proved that severe local inflammation was present: and thus we are furnished with a pathognomonic sign of great importance. The average augmentation of fibrin in inflammation may be estimated at 7; the minimum at 5; the maximum at 10½. It does not appear that in robust athletic persons, the proportion of fibrin is greater than in those of feeble constitution; in the latter it is the globules that are deficient; and it is rather from this disproportion, than from an absolute excess of fibrin, that their greater liability to inflammatory affections arises. Diseases which commence at the same time as the inflammation, or coexist with it, do not prevent the characteristic increase of the fibrin; thus in chlorotic females, the proportion rises to 6 or 7, under this influence. The augmentation is observed at the very outset of the affection; the quantity increases with its progress; and a decrease shows itself when the disease begins to abate. When the disease presents alternations of increase and decline, these are marked by precisely corresponding changes in the quantity of fibrin. It appears that the rise of the quantity of fibrin above the normal standard is not immediately checked by venesection; this does not prove, however, that bleeding is useless; but only that it cannot arrest *instanter* the tendency to the production of an increased quantity of fibrin. It is a curious fact that an augmentation is commonly observable during the advanced stage of phthisis, in spite of the deterioration which the blood must then have undergone; this is probably dependent upon the development of local inflammation around the tubercular deposits. Some experiments performed by M. Andral on the blood of pregnant women seem to lead to the conclusion that, during the first six months, the fibrin is below the normal standard; and that it subsequently varies, usually undergoing an augmentation between the sixth and seventh, and the eighth and ninth months. But further experiments are needed to verify this.

593. It appears obvious, from what has been just stated, that the increase in the quantity of fibrin is not dependent upon the febrile condition, which is secondary to the local inflammation, but upon the inflammation itself. This conclusion is confirmed by the interesting fact that, in idiopathic fever, the proportion of fibrin is diminished instead of undergoing an increase. This diminution was constantly observed by Andral in the premonitory stage of continued fever; in some instances the amount was no more than 1·6 parts in 1000. The proportion of globules was found to have usually, but not constantly, undergone an increase; as had also that of the solid parts of the serum. In ordinary continued fever, in which there was no evident complication from local disease, the quantity of fibrin varied from 4·2 to 2·2; that of the globules from 185·1 to 103·6 (excluding a case in which their amount was only 82·5, which was that of a chlorotic female); that of the solid matter of the serum, from 98·7 to 90·9; and that of the water from 725·6 to 851·9. Hence the quantity of solid matter appears to be usually increased; but the peculiar condition of the disease may probably be stated to be an increase in the proportion of the globules to the fibrin. When, however, a local inflammatory affection developes itself during the course of the fever, the amount of fibrin increases; but its augmentation seems to be kept down by the febrile condition. In typhoid fever,* the decrease in the proportion of fibrin is much more decidedly marked; this does not depend upon abstinence; for it ceases as soon as a favourable change occurs in the disease, long before the effect of food could show itself. In the various cases examined by Andral, the blood furnished a maximum of 3·7 of fibrin, and a minimum of 0·9; in this last case, the typhoid condition existed in extreme intensity, yet the patient recovered. The proportion of globules varies considerably; in an early stage of the disease it is usually found to be absolutely high; and it always remains high relatively to the amount of fibrin. In typhoid fever, then, the abnormal condition of the blood, in regard to the disproportion between the globules and the fibrin, is more strongly marked than in ordinary continued fever; yet the usual augmentation of fibrin will take place, if a local inflammation developes itself. In the eruptive fevers it does not appear that the proportion between the fibrin and the globules undergoes so striking a change as in ordinary continued fever; but the number of cases examined was too small to admit of decided conclusions. By the experiments of Magendie it has been ascertained, that one of the effects of a diminution in the proportion of fibrin is a tendency to the occurrence of hemorrhage or of congestion, either in the parenchymatous tissue, or on the surface of membranes; these conditions are well known to be of frequent occurrence as complications of febrile disorders. A marked diminution of fibrin was noticed also in many cases of the disorder termed cerebral congestion, which commences with headache, vertigo, and tendency to epistaxis, and not unfrequently passes into coma and apoplexy. In Apoplexy, the diminution of fibrin was still more striking; and in general there was found to be an increase of the globules. In one instance the quantity of fibrin on the second day of the attack was found to have fallen to 1·9, whilst that of the globules had risen to 175·5; but on the third day, when the patient's consciousness began to return, the quantity of fibrin was 3·5, whilst that of the globules had fallen to 137·7. It would seem, from the great change in the character of the blood, which was

* M. Andral confines this term to the species characterized by ulceration of the mucous follicles of the intestinal canal.

noticed in this and in other instances, that the want of due proportion between the fibrin and the globules was the cause rather than the effect, of the apoplectic attack.

594. The amount of globules seems to be subject to greater variation within the limits of ordinary health, than is that of fibrin. In the condition which is ordinarily termed a highly sanguineous temperament, or *plethora*, it is chiefly the former that undergoes an increase. Plethoric persons are not more liable to inflammation, than are those of weaker constitution; but, from the quantity of fibrin in their blood being small relatively to that of the globules, they are liable to congestion, especially of the brain, and to apoplexy or other hemorrhage. The effect of bleeding in diminishing this tendency is now intelligible; since we know that loss of blood reduces the number of globules. On the other hand, in that temperament,* which, when exaggerated becomes anæmia, there is a marked diminution of the globules; this temperament may lead to two different conditions of the system. In chlorosis, the globules are diminished, whilst the fibrin remains the same; so that the clot, though small, is firm, and not unfrequently exhibits the buffy coat; in some extreme cases of this disease, the globules have been found as low as 27. The influence of the remedial administration of iron, in increasing the quantity of globules, was rendered extremely perceptible by Andral's analyses; in one instance, after iron had been taken for a short time, the proportion of globules was found to have risen from 49·7 to 64·3; whilst in another, in which it had been longer continued, it had risen from 46·6 to 95·7. On the other hand, bleeding reduced still lower the proportion of globules; thus in one instance, their amount was found, on a second bleeding, to have sunk from 62·8 to 49. The full proportion of fibrin in the blood of chlorotic patients accounts for the infrequency of hemorrhage in them; whilst it also leads us to perceive that they may be, equally with others, the subjects of acute inflammation, which we know to be the fact. A diminution of globules may also coexist with a diminution in the amount, or in the degree of elaboration, of the fibrin; and this condition seems to be characteristic of scrofula. Andral has noticed a diminution in the proportion of globules in other cachectic states, resulting from the influence of various depressing causes on the nutritive powers;—as in a case of diabetes mellitus, in which the patient was much exhausted;—a case of aneurismal dilatation of the heart inducing dropsy—and in several cases of cachexia saturnina.

595. The chief class of cases in which any marked change has been observed in the amount of solid matter in the serum, is that of albuminuria, or Bright's disease of the kidney. The diminished specific gravity of the serum was long ago pointed out by Dr. Christison; but Andral remarks that this is not an accurate criterion, since, if there be a diminished amount of globules (as is not unfrequently the case in this disease), the proportion of water in the whole will be increased, and the specific gravity of the serum thus lowered, without any alteration in its proper quantity of solid matter. According to Andral, the diminution in the amount of albumen in the serum is exactly proportional to the quantity contained in the urine. A case is related by him, under this head, which affords an interesting exemplification of the general facts which have been already attained by his investigations. A woman who had been suffering from erysipelas of the face, and who had lost blood both by venesection and by leeches, became

* The term *lymphatic* has been applied to this temperament; by which term was meant a predominance of lymph in the absorbent vessels.

the subject of albuminuria. The blood drawn at this time exhibited a considerable diminution in the proportion of globules, as well as of albumen,—a fact which the previous loss of blood fully accounted for. After a short period, during which she had been allowed a fuller diet, another experimental bleeding exhibited an increase in the proportion of globules. Some time afterwards, when the albumen had disappeared from the urine, some more blood was drawn; and it was then observed that the albumen of the serum had returned to its due proportion, but that the globules had again diminished, whilst there was a marked increase in the quantity of fibrin. This alteration was fully accounted for by the fact that, in the interval, several lymphatic ganglia in the neck had been inflamed and had suppurated; and that the patient had been again placed on very low diet. "Thus," observes Andral, "we were enabled to give a complete explanation of the remarkable oscillations which were presented, in the proportion of the different elements of the blood drawn at three different times from the same individual; and thus it is that, the more extended are our inquiries, the more easy does it become to refer to general principles the causes of all those changes in the composition of the blood, which, from the frequency and rapidity with which they occur, seem at first sight to baffle all rules, and to take place, as it were, at random. In the midst of this apparent disorder, there is but the fulfilment of *laws;* and in order to obtain these, it is only necessary to strip the phenomena of their complications, and reduce them to their simplest form."

Origin of the Solid Tissues.

596. It has been shown that the Blood contains a substance (Fibrin) which is prepared to become *organized*, or to take upon itself that peculiar kind of molecular arrangement, which is anatomically characterized as *structure*, and which possesses what the physiologist terms *vital properties;* but it has also been shown that the conversion of this Fibrin into organized structure requires the influence of a previously-existing organism. In the development of the embryo, the germ of the first cell appears to be supplied by the male parent; whilst the nutriment at the expense of which it is evolved is supplied by the female. In the subsequent growth of the organism, the materials are derived from the food ingested; and the conversion of these into organized tissue depends upon the properties of the structure already formed, which, whilst itself decaying, liberates the germs of new cells, and thus makes preparation for its renewal. The processes by which these cells are converted into the several kinds of organic structure that compose the fabric of the higher animals, are in many instances very complex; and can only be traced by an attentive examination of their several stages. Whether they are observed, however, in the first development of the embryo, or in the reproduction of lost parts, they seem to be essentially the same. In fact, among the lowest tribes of Animals we find these two conditions blended, as it were, together; for the process of reparation may be carried in them to such an extent, as to regenerate the whole organism from a very small portion of it. In the Hydra, or Freshwater Polype, there would seem to be scarcely any limit to this power; for, if the body of the animal be minced into the smallest possible fragments, every one of these can produce a new and perfect being. In this manner, no less than forty have been artificially generated from a single individval. In ascending the animal scale, we find this reparative power less conspicuous, because exercised with regard to smaller parts only of

the body; but the greater complexity of the changes involved in the process renders it in reality not less considerable than in the lower classes. Thus, the restoration of a bone destroyed by necrosis is a much more extraordinary operation than the growth of an entire Polype from a single fragment; since it involves a far greater amount and variety of actions. Numerous and well-authenticated instances are on record, of the reunion of parts that had been entirely separated from the body, and of the restoration of all their vital properties, and this could only take place through the perfect reproduction of a large number of very different structures. The reappearance of fungous growths, whose organization is of a low character, is a fact with which every surgeon is familiar; and cases occasionally, though rarely, present themselves, in which reproduction of a whole member takes place even in the Human subject.*

597. Before proceeding to describe in detail the mode in which the primordial cells are converted into the several varieties of tissue, it may be desirable to take a general survey of the conditions under which the reparative processes are carried on,—a question of great practical importance, on which very mistaken notions are prevalent. It is the general opinion among British surgeons (founded upon what they believe, but erroneously, to have been the doctrine of Hunter), that Inflammation is essential to the process of Reparation. There is no doubt that, as generally conducted, the healing of wounds is attended by a greater or less degree of inflammation; but it does not thence follow that this morbid condition is essential to the renewal of the healthy state; and in fact it can be shown that, in the majority of cases, the inflammation is injurious rather than beneficial. The following important conclusions are drawn by Dr. Macartney† from a very philosophical comparative survey of the operations of Reparation and Inflammation, as performed in the different classes of animals:—"That the powers of reparation and reproduction are in proportion to the indisposition or incapacity for inflammation;—that inflammation is so far from being necessary to the reparation of parts, that, in proportion as it exists, the latter is impeded, retarded, or prevented;—that, when inflammation does not exist, the reparative power is equal to the original tendency to produce and maintain organic form and structure;—and that it then becomes a natural function, like the growth of the individual, or the reproduction of the species."

598. Guided chiefly by Dr. Macartney's views, we shall treat of the reparative processes under three distinct heads:—*First*, the adhesion of the sides of a wound by a medium of coagulable lymph, or of a clot of blood. *Second*, reparation without any medium of lymph or granulations, the cavity of the wound being filled by a natural process of growth from its walls. *Third*, reparation by means of a new, vascular, and organized substance, termed granulations.

599. The first of these modes of reparation is that which is ordinarily termed *union by the first intention;* of this kind of adhesion, the healing of the incision made in venesection, which usually takes place almost without consciousness on the part of the patient, and with scarcely any inflammation, is a characteristic example; the white line of cicatrix which is left marks the formation of new substance, and is the result of the want of that perfect approximation of the lips of the wound, which may fre-

* See, on the whole of the subject of the comparative powers of reparation in the Animal series, the Author's Principles of Gen. and Comp. Physiol. §§ 586, 587.

† Treatise on Inflammation, p. 7.

quently be obtained in parts where pressure can be more firmly applied, and where the space to be filled up is proportionably thinner. This mode of union is ordinarily considered by British surgeons to be the result of an *adhesive inflammation.* In so regarding it, they conceive that they are following out the views of Hunter; but he expressly states that wounds may heal without any pain or constitutional disturbance, the reunion proceeding "as if nothing had happened;" so that he in effect admits, that reparation of this kind may take place without inflammation. It is well known that if a slight wound, which is thus healing, be provoked to an increased degree of inflammation, its progress is interrupted; and all the means which the surgeon employs to promote union, are such as tend to prevent the accession of this state. The doctrine that the effusion of lymph for the reparation of the tissues is not to be regarded as necessarily a result of the inflammatory process, is not so novel as its opponents have regarded it; since it has been maintained by many eminent observers, even from the earliest times. It is supported by the fact that coagulable lymph may be thrown out by a natural and healthy action, as in the formation of the decidua uteri; and that the surface of a wound is covered with lymph too soon after the receipt of an injury for inflammation to have set in. The only case in which the occurrence of Inflammation can be regarded as salutary, is that in which there is a deficiency of fibrin in the blood, causing a deficient *organizability* of the lymph. It has been seen that the amount of fibrin is rapidly increased by inflammation; and the Surgeon well knows that a wound with pale flabby edges, in a depressed state of the system, will not heal until some degree of inflammation has commenced.

600. When the Liquor Sanguinis of the blood, known as coagulable lymph, is effused between the two edges of a wound, or upon the surface of a membrane lining a closed sac, the following appears to be the history of its organization. The new matter, which is poured out in a fluid state, undergoes a coagulation resembling that of blood; the serum being set free by the concretion of the fibrin, is absorbed; and the fibrinous coagulum speedily attains an almost membranous density. If examined with a microscope at the commencement of the process of organization, it is seen to contain a large number of the exudation-corpuscles already mentioned (§ 559); these originating probably either in the lymph-globules that have circulated in the blood, or in the nuclei of the red corpuscles (§ 578.) In a short time, these corpuscles present the appearance of regular cells, disposed in layers, and adhering together by an intermediate unorganized substance; bearing, in fact, a strong resemblance to the cells of tesselated epithelium. Some hours later, the mass exhibits an evidently fibrous character; and this is due to the adhesion of the cells to each other in lines, their form being prolonged in the same direction. Between these cellular fibres, a considerable amount of cytoblastema or hyaline substance (§ 554) yet remains; and they may be readily separated, or torn in any direction. A vascular rete next makes its appearance, and forms connections with the vessels of the subjacent surface; the first appearance of this network is in the form of transparent arborescent streaks, which push out extensions on all sides; these encounter one another, and form a complete series of capillary reticulations, the distribution of which very nearly resembles that which has been seen in the villi of the intestines (Fig. 41). Before the vascular rete appears, pale-coloured cytoblasts are produced, which, after the completion of the rete, pass over into the nearest capillary veins, being pushed on by the blood which is brought from the nearest arteries; and in this manner the circula-

tion is established. This process appears to be conformable, in all essential particulars, with that which has been observed in the development of the toes of the larva of the Water-Newt, and similar natural growths. The character—whether arterial or venous—which each tube is to assume, depends upon its proximity with some vessel of the subjacent membrane, with which it becomes continuous; but its first formation is not due, as some have supposed, to the simple prolongation of these vessels into the fibrinous mass, since the latter is able of itself to originate a capillary plexus.

601. Although many have doubted whether effusions of *blood* could thus become organized, there seems no valid reason to think that its fibrin would comport itself in any other way, when red particles are included in its coagulum, than when they are absent. That large masses of extravasated blood should exhibit little or no tendency to organization, will not be considered surprising, when it is remembered that only their surface can be in that relation with a living membrane, which has been stated to be essential to the further vitalization of the effused fibrin (§ 583). It has been proved in many instances, however, that coagula of blood completely enclosed within the body possess an incipient vascularity, being capable of injection from the surface beneath;* and there is no valid reason to deny, that the thin layer of blood which remains between the lips of an incised wound, when these are closely brought together, is the medium of their reunion. Whether the red corpuscles aid or retard the process, is yet uncertain (§ 578).

602. To the *second* mode of reparation, attention has recently been strongly directed by Dr. Macartney; and as this, too, is a strictly physiological action, and is one which the surgeon should aim at producing, it will be here discussed somewhat in detail. The Surgeon has, until recently, regarded the processes of granulation and suppuration, which are attended with much local inflammation, and with a considerable amount of constitutional disturbance when the surface is large, as the only means by which an open wound can be filled up. Occasional instances, however, have not been wanting, in which large open wounds have closed up under the dry clot of blood by which they were at first covered over, without any suppuration, or other symptom of inflammation; and in these it has been found that the new surface much more nearly resembles the ordinary one, than does the cicatrix which follows granulation. To Dr. Macartney, however, is due the merit of explaining the *rationale* of this action, which is precisely analogous to that which is concerned in the ordinary processes of growth, and to that reproduction of whole parts which takes place in the lower animals without inflammation. It is termed by him the *modelling* process; and he remarks as characteristic of it that, when it goes on perfectly, and without inflammation, the patients are so completely free from uneasy sensations, as only to be aware of the extent of the injury by their own examination. In this process, the surfaces of the wound do not unite by vascular connection, even when they lie in contact; nor is the space between them filled up with coagulable lymph; but they are smooth and red, moistened with a fluid, and presenting the appearance of one of the natural mucous membranes. "It might be anticipated that, as this mode of reparation bears so strong a resemblance to the natural formation and development of parts, it is the slowest mode; but this is of little account, when compared with its great advantages in being unattended with pain, inflammation, and constitu-

* For a well established case of this sort, see a communication by Mr. Dalrymple in the Medico-Chirurgical Transactions, vol. xxiii.

tional sympathy, and leaving behind it the best description of cicatrix." In the case of large burns on the trunk in children, the difference between the two modes of reparation will frequently be that of life and death; for it often happens that the patient sinks under the great constitutional disturbance occasioned by a large suppurating surface, although he has survived the immediate shock of the injury.

603. The most effectual means of promoting this kind of reparative process, and of preventing the interference of inflammation, vary according to the nature of the injury. The exclusion of air from the surface, and the regulation of the temperature, appear the two points of chief importanee. By Dr. Macartney, thec onstant application of moisture is also insisted on.* He states that the immediate effects of injuries, especially of such as act severely upon the sentient extremities of the nerves, are best abated by the action of "*steam* at a high but comfortable temperature, the influence of which is gently stimulant, and at the same time extremely soothing. After the pain and sense of injury have passed away, the steam, at a lower temperature, may be continued;" and, according to Dr. M., no local application can compete with this, when the inflammation is of an active character. For subsequently restraining this, however, so as to promote the simple reparative process, water-dressing will, he considers, answer sufficiently well; its principal object being the constant production of a moderate degree of cold, which diminishes, whilst it does not extinguish, sensibility and vascular action, and allows the reparative process to be carried on as in the inferior tribes of animals. The reduction of the heat in an extreme degree, as by the application of ice or iced water, is not here called for, and would be positively injurious; since it not only renders the existence of inflammation in the part impossible, but, being a direct sedative to all vital actions, suspends also the process of restoration. The efficacy of water-dressing in injuries of the severest character, and in those which are most likely to be attended with violent inflammation (especially wounds of the large joints) has now been established beyond all question; and its employment is continually becoming more general. Other plans have been proposed, however, which seem in particular cases to be equally effectual. To Dr. Greenhow, of Newcastle, for instance, it was accidentally suggested, a few years since,† to cover the surface of recent burns with a liquified resinous ointment; and he states that in this manner suppuration may be prevented, even where large sloughs are formed, the hollow being gradually filled up by new tissue, which is so like that which has been destroyed, that no change in the surface manifests itself, and none of that contraction, which ordinarily occurs even under the best management, subsequently takes place. A plan has, moreover, been proposed for preventing suppuration, and promoting reparation by the modelling process, which consists in the application of warm dry air to the wounded surface. The experiments made on this have not been entirely satisfactory; but they seem to show that, though the process of healing is much slower under treatment of this kind, it is attended with less constitutional disturbance than is unavoidable in the ordinary method; and it may, therefore, be advantageously put in practice in those cases, in which the condition of the patient requires every precaution against such an additional burthen,—as after amputation in a strumous subject. But of the superiority of this treatment to the water-dressing no evidence has yet been adduced.

604. The *third* method of reparation,—that by granulation—appears to

* Treatise on Inflammation, p. 178.
† Medical Gazette, Oct. 13, 1838.

be a means employed by Nature for the purpose, under the unfavourable circumstances of irritation or a continuance of inflammation; proving that parts, previously in a healthy state, are disposed to heal, in despite of many impediments thrown in their way. The granulation-structure is a special one, formed for a temporary purpose. It is endowed with higher vascularity and a more rapid power of growth, than is possessed by any modification of ordinary tissue; but it is very easily destroyed by injury, or by a higher degree of inflammation. The existence of granulations has been supposed to be necessary to fill up deficiencies; this, however, is not altogether true; as we occasionally find very considerable vacancies filled with lymph, which gradually becomes organized, without being converted into granulations; and the void may be also supplied by the process of natural growth just described. Moreover, it is only in the beginning that granulations take the place of the natural structure; for the approximation of the edges of a wound filled with them, requires that they should be removed by interstitial absorption; so that wounds healed by this process do not exhibit any remains of the new medium. This approximation somewhat resembles that which occurs in open wounds that have never inflamed, being the result of the natural processes of growth, and it does not take place until the inflammation has in great degree subsided; but it differs from the modelling processes in this,—that, as the wound is occupied by granulations, its closure takes place prematurely as it were; so that, when the granulations are subsequently absorbed altogether, a contracted cicatrix is the result. It will be presently seen that the formation of the granulation-structure is intimately connected with the elaboration of pus; and this process, accompanied as it is with such great constitutional disturbance, and involving such a loss of nutritious material, cannot but be regarded as an action to be altogether avoided if possible.

605. We shall now consider, more in detail, the nature of the process of granulation, and of the suppuration which usually accompanies it. Its commencement is exactly conformable to the first stage of ordinary reunion by the first intention; for liquor sanguinis is thrown out, in which exudation-corpuscles present themselves in large numbers. According to Gerber, the transformation of these into a sort of imperfect epithelium may be seen to take place within half an hour. New layers are in the meantime developed; and the most superficial of the exudation-corpuscles, which are exposed to the contact of air, change their character (in the mode described in the next paragraph) and become pus-globules; whilst those in close contact with the subjacent surface become a part of the living organism, and take a share in the processes of exudation and reparation. A new layer of exudation-globules is next deposited over this; and of this the outer portion degenerates as before into pus-globules, whilst the inner part becomes organized into a kind of fibro-cellular tissue, forming granulations. These granulations are themselves extremely vascular; and, as recently shown by Mr. Liston,* the vessels of the subjacent tissue are much enlarged, and assume a varicose character. The bright red colour of the granulations, however, does not depend on their vascularity alone; for the cells themselves, especially those most recently evolved, are of nearly as deep a colour as the blood-globules; and the superficial bleeding which follows even the slightest touch of the granulating surface, does not proceed from blood shed from the new-formed vessels only; the red fluid shed in this manner contains, besides blood-discs, newly-developed red cells, ruddy cytoblasts, pale granules and reddish serum. It is a common property of

* Medico-Chirurgical Transactions, Vol. xxiii.

animal cytoblasts, that they present a red colour on their first formation, when in contact with oxygen; but this hue they lose again, whether they advance to perfect development and become integral parts of a living tissue, or die and degenerate. The process of granulation and suppuration appears to differ from that of simple reparation (the *modelling process* of Dr. Macartney) in this,—that a large part of the exudation-corpuscles deposited on the wounded surface degenerate into pus in the former case, whilst none are thus wasted in the latter;—but that the existence of inflammation occasions a more copious supply of fibrin in the former case, and increases its tendency to become organized; the filling-up of a wound with cellular granulations being thus a much more rapid process, than that renewal of the completely-formed tissues which may take place in the absence of inflammation. The imperfect character of the granulation-structure is shown by the almost complete disappearance of it, after the wound has closed over. The portion of it in immediate contact with the subjacent tissue, however, appears to undergo a higher organization; for it becomes the medium by which the cicatrix is made to adhere to the bottom of the wound. It is very liable to undergo changes which end in its disintegration; as is evident from the known tendency to re-opening in wounds that have been closed in this manner.

606. Various opinions regarding the nature and origin of the pus-globule have been given by different observers; but the account of their degeneration from the exudation-corpuscle, which is here given on the authority of Prof. Gerber, seems to have the greatest probability. On the exudation-globules of the surface, a number of delicate lines radiating from a centre are first perceived, dividing the periphery into six or eight segments; these lines become more and more distinct, and the capsule appears as it were torn or cleft, but without any separation of parts; the nucleus also exhibits marks of division; and finally the globule presents the aspect of a mass of granules, the segments of the envelope and the divisions of the nucleus (which were at first linear and sharp in appearance) having become rounded off. The true pus-globules thus formed are mixed in the fluid secretion with oil-globules and albuminous globules; the proportion of these varies at different stages of its formation. The younger the fluid, the more of the fibrinous globules does it contain, and the smaller is the quantity of its oily matter; in that which is more mature, the fibrinous part has diminished whilst the oil has increased; and in this we find the largest portion of the granular pus-globules, which have the characters of albumen. There is no doubt that the contact of air tends very greatly to favour the production of pus; and Gerber and others are of opinion, that no true suppuration can take place in situations to which it has not access: but this does not seem consistent with numerous well-ascertained facts. It is yet to be ascertained whether the peculiar form of pus-globule just described is to be regarded as so far characteristic of true pus, that, when it is absent, the existence of pus is not to be admitted. Many puriform fluids, which resemble pus not only in appearance but in chemical composition, are destitute of it, containing in its stead irregular granules of softened fibrin. Until recently it has been common to regard as pus the fluid that often results from the softening of fibrinous masses; but Mr. Gulliver* has shown the complete fallacy of this idea; and he has also pointed out the frequency of the instances in which the mistake is liable to be made. Dr. Barry states that he has distictly seen true pus-globules originate in blood-corpuscles; this observation

* Medico-Chirurgical Transactions. Vol. xxii.

will not be inconsistent with the above statements, if the exudation-corpuscle has the origin which Dr. B. attributes to it (§ 578). The introduction of a small quantity of pus into the blood is capable of inducing very important changes in its structure and properties; for, if it be stirred into the fluid when freshly drawn, it prevents its coagulation; and there can be little doubt, from the phenomena of disease, that, when absorbed from surfaces or cavities in which it is formed, into the general mass of the blood, it gives origin to that tendency to the extended production of pus, which shows itself in secondary or metastatic suppurations.

607. In ill-conditioned sores, of which the surface is not in any part giving origin to new tissue, the discharge does not contain the true pus-globule; but in place of it there are found what have been termed ichor-corpuscles, which are evidently altered blood-discs. The ichorous fluid, when the sore is of the phagedenic kind, is seen also to contain the debris of the solid tissues which are undergoing removal; and it is probable that the altered red-particles of the blood only find their way into it accidentally, through the destruction of the coats of the superficial vessels. They are peculiarly abundant in the discharge of glanders. It has been supposed by some (by Gerber among the rest) that the ichor possesses a disintegrating power, and that the progressive deepening and extension of the sore is directly owing to its agency; the same was formerly supposed with respect to pus; but the idea is now known to be incorrect in regard to the latter, and it does not appear to have any better foundation when applied to the former. The surgeon endeavours to change the character of an indolent and ill-conditioned sore, by stimulating applications, or even by removing its surface with the knife or with caustic; in the latter mode, the sore is turned into a fresh wound, in which, if other circumstances are favourable, the process of reproduction may take place, accompanied by perfect suppuration.

608. Another degenerated form of the exudation-corpuscle, is that which forms the matter of Tubercle. This term has been used by pathologists in a great variety of senses; being applied to substances differing very much in their capability of organization. In this country, the matter of the tubercle is usually regarded as unpossessed of organization, and as existing like a foreign body in the tissues in which it is deposited. It is now very generally considered, that the exudation of tubercular matter is most commonly (if not always) a result of inflammation; and that it is deposited in scrofulous subjects in the same situation in which organizable lymph would have been effused in sounder constitutions. This view seems confirmed by the fact, that every gradation may be detected, from the completely-organized fibrinous matter which remains in tissues that have been condensed by inflammation, to the softest tubercle. Of the former, we have a characteristic example in hepatization of the lung; the organization of such plastic exudations appears to take place most favourably when the infiltration is slow, and, when once organized, they commonly undergo no change for a long period. They are not disposed to soften, or to pass into suppuration; but they are sometimes removed by the ordinary process of slow decomposition and interstitial absorption. When the exudation takes place more rapidly, complete organization, or transformation into a fibrous tissue [illegible] takes place in the parts of the deposit that are in contact with the living walls of the cavity, and the interior portions [illegible] the exudation [illegible] themselves in true fibrous deposits. This kind of matter is very [illegible] to undergo softening, either on its first deposition, or,—[illegible] as frequently happens [illegible] its serum be absorbed, and [illegible]

remain for some time as a dry mass,—on some subsequent effusion of serum. In other instances not even the exterior of the deposit exhibits any thing more than the cellular organization; and sometimes nothing but a hyaline substance is found. These, however, may be considered as transitory conditions; since fibrin, however poured out, has always a tendency to become organized, when in contact with a living tissue.

609. The less organizable matter, to which the name of Tubercle is ordinarily restricted in this country, appears rather to consist of albumen, with a greater or less admixture of fibrin. It generally exhibits no other trace of structure, than a congeries of minute albuminous granules, mingled with shapeless flakes or filaments; but cytoblasts and cells may be occasionally detected in it, especially when it is recently formed. The granules are described by Mr. Gulliver as extremely variable in magnitude, their diameter ranging from 1-30,000th to 1-8000th of an inch; they form nearly the entire mass of caseous tubercle. The shapeless particles are considered by him as probably imperfect, degenerating, or blighted cells or nuclei; they usually vary from 1-6000th to 1-2000th of an inch in diameter. These may be seen in crude or mature tuberculous matter, and frequently in the smallest caseous tubercles, especially of the serous membranes. The granular matter preponderates, as the tuberculous mass increases. The most common size of the cells is from 1-2600th to 1-1140th of an inch in diameter. They may be frequently recognized in grayish miliary tubercles, either of the lungs or serous membranes; but as the tubercles increase in magnitude, the well-marked and complete cells disappear, probably degenerating into the corpuscles and granular matter.* Hence it appears that the difference between a deposit of tubercle, and the effusion of plastic lymph, consists in this;—that the former is composed of the albuminous constituent of the blood, a mere chemical compound which is not prepared to undergo organization until it has passed through the condition of fibrin;—whilst the latter is a portion of the vitalized fibrin, which possesses within itself the tendency to organization, and only requires the contact of a living membrane to enable it to pass into a regular structure. Now it has been seen that it is a peculiar tendency of the inflammatory condition to develope an increased quantity of fibrin in the blood (§ 592); and it is scarcely possible to suppose that this fibrin is generated anywhere else than in the part affected. Hence it may be questioned, whether the process by which tubercle is thus generated, is really deserving of the title of Inflammation. Indeed it is almost indubitable, that tubercular matter may be deposited by a perversion of the ordinary process of Nutrition, without anything like an inflammatory state. Thus, in the one case, as in the other, the existence of a scrofulous diathesis occasions *that* to be deposited as unorganizable albumen, which, in persons of sound constitution, would have had the form of organized fibrin.

610. A deposit of albuminous matter, under a somewhat different form, takes place in what is termed granular degeneration, or Bright's disease, of the kidney. In the earlier stages of this disorder, the albumen is deposited in the tortuous uriniferous canals of the cortical substance; in the fully-formed disease, however, it is met with among and between the other tissues also.

* See Gerber's General Anatomy, and Mr. Gulliver's Appendix, from which the materials of the preceding paragraphs have been almost entirely derived.

Formation of the Tissues.

611. From the primordial cells, of which the whole fabric of the embryo, or the tissue of a newly-formed part, is composed, all the animal tissues, various as they are in structure and in properties, are gradually elaborated. Their variety is much greater than that which exists in Plants; and this is exactly what we should expect, when we take into account the much greater number of entirely-different functions to be performed. Nevertheless it may be remarked, that the tissues which are essentially concerned in the performance of the Organic functions, and in the mechanical support of the frame, are produced from the original cells by a transformation of nearly the same kind with that which takes place in Vegetables; and that it is in those which minister to the Animal functions, that we find the greatest departure from this plan. Among the former, we shall have to notice that the cells, or the bodies originating in them, remain to a great degree independent of one another, as in Plants; whilst, in the Muscular and Nervous substance they are brought into closer relation, in order that they may perform those peculiar functions, which evidently require the conjoint and consentaneous actions of a large mass of tissue.

612. The transformations alluded to may be of several kinds. The cells may retain their original form, but may undergo a change in the character of their contents; and this change may impart to them a character entirely new. Such, for example, occurs in regard to adipose or fatty tissue, which is nothing else than a mass of cells filled with oily substances; whilst, on the other hand, in the horny tissues, there is a deposit within them of a peculiar horny matter; in cartilage there is a corresponding deposit of a gelatinous substance; and in bone, calcareous matter is laid down. These deposits appear to take place on the same general plan with those which are met with in the Vegetable tissues. We find, for instance, oily matter stored up in one set of cells; whilst in another, we find a lining of *sclerogenous* deposit,* imparting great density to the structure; and in the heart-wood, not only the cells, but the woody tubes and the ducts, are blocked up in this manner. In all these instances, however, the membranous substance of which the tissue is composed, retains its original composition; being found, when the subsequent deposits have been dissolved away, to possess the same chemical characters as it at first presented. To the membranous element of the Vegetable structure, the term *Cellulose* has been given; and its composition is found to be nearly identical with that of the starchy matter in which it originates (§ 556). It is probable that the same general doctrine may be applied to the Animal structures; although the question has not yet been so fully investigated, as to enable a positive statement to be made regarding it. Wherever the membranous matter can be obtained free from extraneous deposits, it appears to possess the chemical characters of Fibrin. This is especially the case with Muscular tissue, which has been generally regarded as the only part of the body into the composition of which fibrin (as such) enters. But there has evidently been great misapprehension on the subject, arising from the close correspondence in the merely-chemical relations of Fibrin and Albumen; and there can be little doubt that, in most, if not all, the instances, in which the latter has been set down as an element of animal *tissues*, we should substitute the former. The *fluids* which these tissues contain (as serum and the humours of the eye), and the secretions discharged by them, are easily shown to contain albumen; but there is no

* See Principles of General and Comparative Physiology, §§ 26, 404.

proof that albumen ever becomes organized, without passing through the condition of fibrin. One of the few chemical differences between them, is the power which fibrin possesses of decomposing the peroxide of hydrogen; of this albumen is destitute; and when this test is applied to the animal tissues, it is found that many which are not ordinarily supposed to contain fibrin, possess the power to a degree that satisfactorily indicates the presence of that element.

613. We have, then, additional reason for regarding Fibrin as the sole organizable material of the Animal body; and, wherever any ingredient entirely different can be proved to exist in its texture, we shall consider this as an extraneous deposit. The most important of these ingredients, which enters into a very large proportion of the Animal tissues, and which may be considered as holding the same rank in them with sclerogen among Plants, is that which is known under the name of Gelatin. This may be obtained by boiling portions of skin, cellular tissue, serous membrane, tendon, bone, &c., in water, for some time; after which the decoction is allowed to cool, when it solidifies into a jelly of greater or less thickness. Some tissues dissolve readily in this manner; and little residual (or fibrinous) substance is left; this is especially the case with cellular tissue, serous membranes, and (in a less degree) with skin. Others require a long boiling for the extraction of any gelatin, and even then it is obtained in but small quantity; of this kind are the elastic tissues and some forms of cartilage. A peculiar modification of this principle exists in most of the permanent cartilages, and will be described when they are treated of (§ 624). Gelatin is not found in the blood, nor in any of the healthy fluids; and some chemists are of opinion that it is rather a *product* of the operation practised to separate it, than a real constituent of the living solids. This idea is inconsistent, however, with the fact, that the gelatinous tissues will exhibit, without any preparation, the best-marked of the chemical properties which are regarded as characteristic of gelatin,—that, namely, of forming a peculiar insoluble compound with tannin; and the tanno-gelatin which may be obtained by precipitating gelatin from a solution, and that which results from the action of tannin on animal membrane, appear to be precisely analogous in every respect, save the presence of structure in the latter, and its absence in the former. Gelatin is very sparingly soluble in cold water; by contact with which, however, it is caused to swell up and soften. It is readily dissolved by hot water; and forms so strong a jelly on cooling, that 1 part in 100 of water becomes a consistent solid. Its reaction with tannic acid is so distinct, that 1 part in 5000 of water is at once detected by infusion of galls. The composition of Gelatin, according to Mulder,* is 13 Carbon, 10 Hydrogen, 2 Nitrogen, 5 Oxygen; if these numbers be multiplied by three, we shall have very nearly the same composition with protein (§ 455), with the exception of the oxygen, which would be in excess; so that we may regard the relative proportions of the carbon, hydrogen and nitrogen as almost identical in the two compounds, but consider these as additionally oxidized in gelatin. As a large quantity of this latter substance is continually being formed from the blood, we may perhaps regard the demand for oxygen, which will be thus occasioned, as one of the chief causes of the disappearance, from the respired air, of a larger amount than is necessary to form the carbonic acid that is exhaled (§ 533). As there is no valid reason to believe that gelatin ever undergoes

* The results of the analysis of Scherer are very different; but he does not seem to have employed pure gelatin.

organization, we may not unreasonably suppose that this principle is elaborated at the expense of the albumen of the blood, rather than from the fibrin. A kind of sugar may be obtained from gelatin, by boiling it with caustic alkali; this crystallizes in large prisms, which are colourless, taste sweet, and feel gritty between the teeth; it is soluble in 4½ parts of water, and is taken up in small quantity by alcohol. This fact is one of much interest in regard to certain pathological relations of gelatin.

[The term nutrition may be not improperly limited to the act by which the organizable plasma is converted into solid tissue. This fibrinous plasma is prepared for organization by the assimilating process just described; and if withdrawn from the interior of the living body, it spontaneously passes into a state which presents a definite organization. Hence, the coagulation of fibrin is clearly not the result of its *death*, as was formerly supposed; for this coagulation is the first stage of its organization, when plastic lymph is poured out on a living surface; and even when the process takes place after the complete withdrawal of the fluid from the living body, a fibrous arrangement, as distinct as that which is presented by fibrin coagulated in the living body—up to the time when vessels appear in the newly-forming tissue, is seen in the clot. The fibres may form by their interlacement an areolar tissue; or by their parallel arrangement a distinct membrane. This fact has been noticed by various observers from the time of Haller; but it has been overlooked by many recent physiological writers, and particular attention has lately been directed to it by Mr. Addison and Mr. Gulliver. The former has studied the fibrous arrangement in the act of being formed in the buffy coat; and he has remarked that corpuscles are included in its areolæ, which he believes to be identical with the colourless corpuscles of the blood. Mr. Gulliver has pointed out the same appearance in thin slices of ordinary coagula rendered hard by boiling:* and here, too, there are interspersed among the fibres pale corpuscles, which are termed by Mr. Gulliver "organic germs," as well as bodies that resemble nuclei of similar cospuscles. The same arrangement of fibres has been shown by Mr. Gulliver to exist in the false membranes which are produced on inflamed serous surfaces, by the more or less complete organization of fibrinous exudations. In such situations, the fibres are mingled with corpuscles, (termed by other authors "exudation cells,") which seem to be the same "organic germs" in an altered condition.† These corpuscles may form a larger or smaller proportion of the exudation; if they are merely scattered amongst the fibres of the coagulum, and the chief part of it be composed of hardened fibrin, the membrane will be tough; but if the exudation be chiefly composed of these corpuscles, with but a small amount of fibres between them, the membrane will be quite friable, and will approach towards the character of a purulent exudation.

The fibrous aggregation of the particles of fibrin seems, therefore, to be the real process of coagulation, whether upon a living or a dead surface. By Dr. Barry it is imagined that the appearance of fibres in the coagulum is due to the rupture of some of the blood discs in which he believes fibres to be generated, and the consequent escape of the latter; but it seems to be forgotten by him that fibrin will coagulate without any blood discs,—as when the latter are separated by filtration, according to Müller's celebrated experiment upon frog's blood,—or when the chyle, in which no blood-discs

* See note by Mr. Gulliver to p. 31 of Gerber's General Anatomy.

† See Mr. Gulliver's contributions to the Minute Anatomy of Animals, Part iv. Philos. Magazine; Oct. 1842.

are to be found except by an accidental admixture, is withdrawn from the thoracic duct. Moreover, as Mr. Gulliver's figures, (Gerber's Anatomy, Figs. 244–6,) all copied accurately from nature, clearly show, a small portion of coagulated fibrin contains a far larger number of fibres, than we can imagine to be contained in the number of blood-discs that would fill the same space. The Author has lately discovered a very interesting example of a membrane composed almost entirely of matted fibres, which so strongly resembles the delineations of fibrous coagula given by Mr. Gulliver, that he cannot but believe in the identity of the process by which they are produced. This is the membrane inclosing the white of the egg and forming the animal basis of the shell. If the shell be treated with dilute acid a tough membrane remains, exactly resembling that which lines it; and if the hen has not been supplied with lime there is no difference between the two membranes even without the action of acid on the outer one. Each of these membranes consists of numerous laminæ of most beautifully matted fibres intermixed with round bodies exactly resembling exudation cells. It is in the interstices of these fibres that the calcareous particles are deposited which give density to the shell; these membranes are formed around the albumen which is deposited upon the surface of the ovary during its passage along the oviduct, from the interior of which the fibrinous exudation must take place. All these facts clearly indicate, that for the reparations of injuries, *inflammation* is not an essential change; since the ordinary fibrin which is continually being applied to the purposes of nutrition, is capable of passing spontaneously into the organized condition, and thus of forming a regular tissue, for the more complete organization of which, nothing is required but the extension of vessels into it from the subjacent surface. Thus a strong confirmation is afforded to Dr. Macartney's doctrine, that the reparation of injuries is best effected by a process resembling the ordinary nutrition of the tissues; and that our therapeutic efforts should be directed to promote this, and to keep down inflammation.

The doctrine of Schwann respecting the development of fibrous as well as other tissues from cells appears to require some modification, since we thus see fibres produced by the simple consolidation of the plasma without an intervening development of cells. Yet if the preceding doctrines be correct, the agency of cells is still required for their production, though in an entirely different mode; since the fibrinous plasma in which the fibres originate is itself elaborated by the cells floating in the circulating fluid. The same remark applies to the other instances in which a tissue appears to be produced without the intervention of cells. Thus the essential part of a mucous membrane, according to Bowman and Goodsir, is a delicate structureless lamella; in the production of which cells appear to have no concern. A similar homogeneous membrane forms the lining of the arteries; but the membrane contains minute particles, which appear to be the germs of the epithelium-cells that are to be developed on its surface. A continual supply of such germs must be required where the epithelium-cells are being constantly thrown off, as is the case with those of the stomach and intestinal canal and with secreting surfaces in general. These germs or reproductive granules have probably been prepared by those *assimilating cells*, the influence of which on the plasma has prepared it to pass into the condition of membrane.

There can be no doubt, however, that the function of the plasma or liquor sanguinis is, in general, to supply the material for the nutrition of the previously-formed tissues,—that is, for the reparation of their waste, by the production of new tissues like their own. As to the mode in which this is

accomplished there is much that is still very obscure, notwithstanding the recent vast increase in the amount of knowledge on the subject. It is certain that a large proportion of the tissues are produced in the embryo, from the cells of which alone it is composed at an early period; these cells undergo various kinds of metamorphoses, the nature of which will be detailed hereafter. But, according to Dr. Barry, many of these tissues which make their appearance in the midst of others,—the crystalline lens for example,—originate in cells which he believes that he can trace back to the *red* corpuscles of the blood. Regarding the validity of this statement, materials are yet wanting for a positive decision; for those which Dr. Barry's paper contains can scarcely be regarded as decisive. The origin of tissues from the *colourless* corpuscles appears to be a much more probable supposition. The "exudation cells" which are found in the lymph effused on cut surfaces, and the pus-globules into which these may be converted by the action of air or other causes, bear so strong a resemblance to the colourless corpuscles, that it is difficult to refer them to any other origin. This, indeed, is the view of their nature entertained by Barry and Addison; and it is only by referring the colourless corpuscle itself to the red particle that they can trace back the greater number of tissues to the latter; the colourless corpuscles being in their view an intermediate stage of development between the ordinary red particles and the first cells of newly-forming tissue. The determination of this last question is a work that cannot be accomplished, except by an extensive series of observations carried on through a great range of species.

But even supposing that the *origin* of any mass of tissue should be traced back to either kind of the cells that are floating about in the blood, we are not thence to decide that the *continued nutrition* of the tissue is performed in the same manner. The muscular fibre once formed, may be able, for any thing that we know to the contrary, to produce the germs of other fibres, by the materials elaborated from the blood, without any direct supply of cells or fibres from it. We *know* this to be the case in regard to cartilage, the cells of which are continually undergoing increase by a process of multiplication exactly conformable to that which takes place in the early state of the embryo; and we know that this tissue is not supplied with blood in any other way than by the transudation of the plasma through its substance. Again, on the surface of mucous membranes there is a continual new development of epithelial cells; these can scarcely be altered blood-corpuscles, as Barry and Addison consider them to be, since bodies of such large size could not make their way through the basement membrane without sensible pores, which certainly do not exist. There seems little doubt that the rapid renewal of the epithelium-cells, which is continually taking place on many of the mucous surfaces, is due to the development of germs contained in the basement membrane at the expense of the fluid brought to its attached surface by the vessels ramifying beneath it. That Dr. Barry and Mr. Addison should see a strong resemblance between blood-corpuscles and incipient epithelium-cells is not surprising, when it is considered, how much alike *all* cells are in some or other of their stages of production; and when the *impossibility* (for such it clearly appears) of this transformation is considered, much doubt is necessarily cast on the validity of the other inferences of those observers. If *similarity* alone is to be taken as a proof of *identity*, then the identity of the chyle and lymph-globules with the colourless corpuscles of the blood is a necessary inference.

The foregoing observations are not intended to express any decided opinions on the subject of the formation of the tissues; since the whole ques-

tion appears to the Author to be at present *sub judice*. In his own mind, however, there is a decided preponderance of evidence in favour of the opinion, that the perpetual reproduction of tissue which constitutes the act of Nutrition, is due to the development of cell-germs in the tissues themselves, at the expense of the fibrin of the blood; and that the use of the *white* corpuscles (of which the analogues are found in the circulating fluid of all animals) is to elaborate that fibrin; whilst the function of the *red* corpuscles (whose office must be of a more special nature, since they are only to be found in Vertebrata,) is to serve as the carriers of oxygen and carbonic acid. But the determination of it has no importance in regard to the principle which it is here attempted to develope. Whether or not it be true that the tissues have their origin in the red corpuscles of the blood, as Dr. Barry maintains, they are developed by the agency of cells; and these cells are descended, more or less remotely, from those of which the foundations were deposited in the germinal vesicle by the act of fecundation. The doctrine of cell-life is as true, therefore, when applied to animal as to vegetable nutrition.—C.]

614. Not only is the chemical constitution of the tissues altered, subsequently to their first organization, by the deposition of gelatinous, oily, calcareous, and other matters, but their absolute form is changed. Instead of the original aggregation of isolated cells or vesicles, we not unfrequently meet with a fabric having a completely fibrous character, with no evident remains of the original tissue. In regard to the origin of the constituent fibres, there is yet some uncertainty. Those of the tissue ordinarily known as cellular, with its modifications, serous membrane, skin, mucous membrane, &c., are probably to be regarded as formed by the aggregation of very prolonged cells (analogous to those of which woody fibre is composed in Plants) which are formed in fasciculi within the original or primordial cells; of the origin of this kind of structure, hair seems to afford a very good illustration, though it is different in other respects (§ 635). On the other hand, muscular and nervous fibres, which are much larger, are to be regarded as tubes, analogous to the ducts of plants, and formed by the fusion of a number of cells originally distinct, and retaining their several nuclei (§ 110 and 374), from which the contents of the tube are probably derived. A brief account will now be given of the structure, development, and chemical composition of the principal forms of tissue in the Animal body, especially in that of Man.

{The following table, extracted from the Physiological Anatomy of Dr. Todd and Mr. Bowman, strikes the Editor as presenting the best general view of the various tissues which he has yet seen. No satisfactory arrangement can, he thinks, be constructed, based on any one principle of classification.

TABULAR VIEW OF THE TISSUES OF THE HUMAN BODY.

1. Simple membrane, homogeneous, or nearly so, employed alone, or in the formation of compound membranes.	Examples.—Posterior layer of the cornea.—Capsule of the lens.—Sarcolemma of muscle, &c.
2. Filamentous tissues, the elements of which are real or apparent filaments.	White and yellow fibrous tissues.—Areolar tissue.
3. Compound membranes, composed of simple membrane, and a layer of cells, of various forms (epithelium or epidermis), or of areolar tissue and epithelium.	Mucous membrane.—Skin.—True or secreting glands.—Serous and synovial membranes.
4. Tissues which retain the primitive cellular structure as their permanent character.	Adipose tissue.—Cartilage.—Gray nervous matter.

5. Sclerous or hard tissue.	Bone.—Teeth.
6. Compound tissues	
a Composed of tubes of homogeneous membrane, containing a peculiar substance.	Muscle.—Nerve.
b. Composed of white fibrous tissues and cartilage.—M. C.}	Fibro-cartilage.

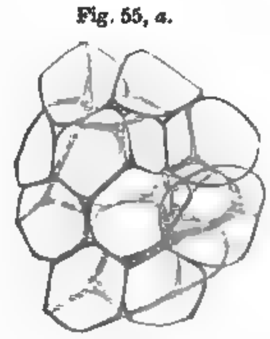
615. There are a few instances in which nucleated cells, resembling those of the primordial fabric, are seen even in the adult body. The most striking examples of this are to be found among the inferior members of the class of Fishes. Thus, in the Myxinoid family, there is no true Vertebral column, but its place is occupied by a gelatinous tube, termed the chorda dorsalis, which consists entirely of nucleated vesicular tissue, and which is precisely analogous to the structure occupying the same situation in the early embryo of higher animals. In the Short Sun-fish, a corresponding form of tissue forms a thick covering to the body, replacing the true skin. And in the Lancelot (a little fish which is deficient in so many of the characters of the Vertebrated division, that many naturalists have doubted its right to a place in the class), a considerable portion of the fabric is made up of a similar parenchyma. The only analogous instance which has yet been pointed out in the higher animals, is that of the nucleated cells which are found in the substance of the Liver, and of other glands (§ 653, Fig. 60).

616. The *Pigment-cells*, which give colour to the skin, and of which the pigmentum nigrum of the eye is entirely composed, usually exhibit the original form of the cell with little alteration. On the choroid coat of the eye they are seen as a kind of pavement, having somewhat of a polyhedral shape, and lying in a very regular manner with some intercellular substance interposed between them. In the skin of Man they are scattered through the ordinary epidermic cells; and its colour is determined by that of their contents. There is no distinct coloured layer, as was formerly supposed; but the cells are more closely aggregated in some parts than in others. This is as much the case in the European, however, as in the Negro; in the former, they are concerned in producing the spots termed freckles, and others of a similar kind. In some animals, the pigment-cells of the skin frequently undergo a change of form, being elongated in many directions into hollow fibres, which, meeting other formations of the same kind, produce a more or less perfect net-work of star-shaped cells. This change is best seen in the skin of the Batrachia, where the cells are frequently isolated; a good example of it is shown in Fig. 45 (p. 349). The black colour is given by an accumulation, within the cell, of a number of rounded granules, which, when separately viewed, are found to be transparent, not black and opaque. The chemical nature of the black pigment has not yet been made evident; it has been shown, however, to have a close relation to that of the Cuttle-fish ink; and to contain a larger proportion of carbon than most other organic substances, every 100 parts containing 58½ of this element. The nucleus of the pigment-cells may generally be traced, as a clear spot.

617. The *Fat-cells*, of which Adipose tissue is composed, also permanently exhibit the original type of structure in its simplest form. This tissue is usually diffused over the whole body, filling up interstices, and forming a kind of pad or cushion for the support of moveable parts. Even in cases of great emaciation, some fat is always left; especially at the base of the heart, around the origin of the large vessels; in the orbit of the eye; in the neighbourhood of the kidney; in the interior of the bones; and within the spinal canal, between the periosteum and the dura mater. The fat-cells are usually spherical or spheroidal; sometimes, however, when

closely pressed together without the intervention of any intercellular substance, they become polyhedral. The nucleus is not always to be distinguished;—perhaps in consequence of its having passed to the interior of the cell.

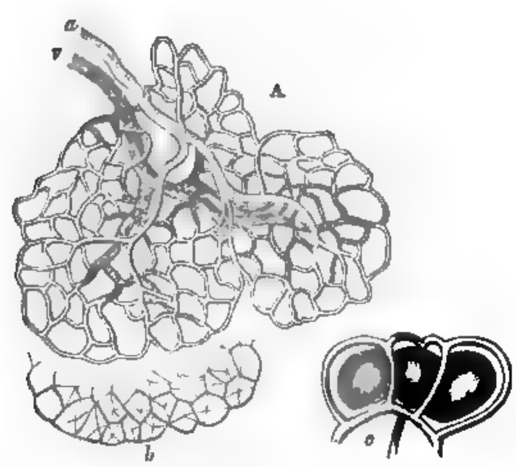
Fig. 55, *a*.



Fat vesicles, assuming the polyhedral form from pressure against one another. The capillary vessels are not represented.—From the omentum; magnified about 300 diameters.

{The *Fat-cell* is composed of the *adipose tissue*, a closed vesicle formed by a membrane of extreme tenuity, and the material which it contains, the *fat*. The membrane is perfectly homogeneous and transparent, about the $\frac{1}{10000}$th of an inch thick, and is moistened by a watery fluid, for which it has a greater attraction than the fat it contains. Each vesicle is a perfect organ, from $\frac{1}{300}$th to $\frac{1}{800}$th of an inch in diameter, with capillaries ramifying on its exterior. When the fat-cells exist in any number their arrangement is usually lobular, with an investment of areolar (cellular) tissue, which favours motion and the distribution of the blood vessels. The vessels enter the interlobular clefts, ramify through their interior, as a solid

Fig. 55, *b*.



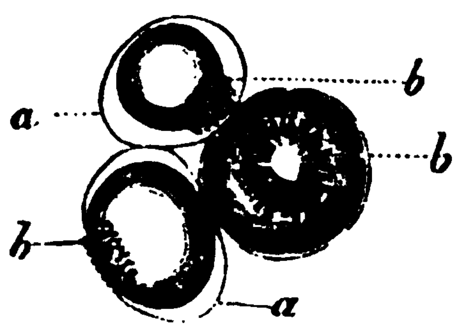
Blood-vessels of Fat:—A. Minute flattened fat-lobule, in which the vessels only are represented. *a*. The terminal artery. *v*. The primitive vein. *b*. The fat vesicles of one border of the lobule, separately represented. Magnified 100 diameters.—B. *Plan* of the arrangement of the capillaries on the exterior of the vesicles: more highly magnified.

capillary net-work, occupying the angles formed by contiguous sides of the vesicles, and anastomose with one another at the points these angles meet.—M. C.}

The consistency of the substance contained in the fat-vesicles varies in different animals, according to the proportions of the organic elements that enter into its composition. These elements are known under the names of stearine, margarine, and oleine; the two former, which are solid when separate, being dissolved in the latter, at the ordinary temperature of the body.

{A spontaneous separation of these proximate principles may sometimes be detected within the human fat-vesicle. The stearine collects in the form of a small star on the inner surface of the membrane; (fig. 55, *b. b. b.*); the elaine occupying the remainder of the vesicle, except where there is an unusually small quantity of fat, when we see a little aqueous fluid interposed between the elaine and the cell-membrane. This offers the best condition for the investigation of the membrane.—M. C.{

Fig. 55, *c.*



Fat vesicles from an emaciated subject:—*a. a.* The cell-membrane. *b. b. b.* The solid portion collected as a star-like mass, with the elaine in connection with it, but not filling the cell.

That the thick oil thus formed does not escape from the fat-cells during life, may be attributed to the moistening of their walls by the aqueous fluid circulating through the body. In all fixed oils, which are fluid at common temperatures, a portion of the solid constituents of fat exists: these may be separated by exposure to cold, which congeals them, leaving the elaine fluid. All these substances are regarded by chemists in the light of salts; being compounds of acids—the stearic, margaric, and oleic—with a common base, to which, from its sweetish taste, the name of *glycerine* has been given.

618. *Stearine* is the essential constituent of nearly all solid fats, and preponderates in proportion to their consistence. It exists largely in mutton-suet; from this it may be obtained by the action of ether, which takes up all the oily matter. It is crystalline, like spermaceti; it is not at all greasy between the fingers, and melts at 143°. It is insoluble in water, and in cold alcohol and ether; but it dissolves in boiling alcohol or ether, crystallizing as it cools. It is composed of two proportionals of stearic acid to one of glycerine, with two proportionals of water. The stearic acid (which is the substance of which the *stearine candles* are composed) may be obtained by causing the stearic acid to combine with a stronger base, such as lime or potash, and then setting it free from this by a stronger acid. *Margarine* exists in small quantity, along with stearine, with most fats; but it is the principal solid constituent of human fat, which in this respect resembles olive oil, rather than the other animal fats. It corresponds with stearine in many of its properties; but it is much more soluble in alcohol and ether; and it melts at 118°. Its composition is analogous (except in the presence of an additional atom of water) to that of stearine, to which indeed it bears a close relation,—margaric acid being procurable from stearic acid, by subjecting it to dry distillation. *Olein* exists in small quantity in the various solid fats; but it constitutes the great mass of the liquid fixed oils. The tendency of these to solidification by cold depends upon the proportion of stearine or margarine they may contain; for olein itself remains fluid at the zero of Fahrenheit's thermometer. It is soluble in cold ether, from which it can only be separated by the evaporation of the latter. Its composition is analogous to that of margarine; for it consists of two proportionals of oleic acid united with one of glycerine and two of water. *Glycerin*, the base of all the fatty acids, may be obtained from any fatty matter by saponifying it with an alkaline base, by which this compound is set free. It cannot be obtained in a solid form, but may be brought to the consistence of a thick syrup. It dissolves in water and alcohol; but is insoluble in ether. It has a sweetish taste, whence its name is derived; and it is remarkable for its solvent powers, which are scarcely inferior to those of water. It is regarded as a hydrated oxyde of a hypothetical base, glyceryl, the composition of which is stated

by Liebig to be six Carbon united with seven Hydrogen. Glycerin is composed of one proportional of this, with five Oxygen and one Water. The following table represents the composition of the fatty acids, and of the compounds just mentioned.

Stearic Acid . .	68 Carbon, 66 Hydrogen, 5 Oxygen.
Margaric Acid . .	34 Carbon, 33 Hydrogen, 3 Oxygen.
Oleic Acid . . .	44 Carbon, 39 Hydrogen, 4 Oxygen.

	Stearine.	*Margarine.*	*Oleine.*
1 atom of glycerine	6 C, 7 H, 5 O	6 C, 7 H, 5 O	6 C, 7 H, 5 O
2 atoms of acid . .	136 C, 132 H, 10 O	68 C, 66 H, 6 O	88 C, 78 H, 8 O
Water (1 or 2 atoms)	2 H, 2 O	1 H, 1 O	2 H, 2 O
Total	142 C, 141 H, 17 O	74 C, 74 H, 12 O	94 C, 87 H, 15 O

619. Besides the support combined with facility of movement, which Fat affords to the moving parts of the body, it answers the important purpose of assisting the retention of the animal temperature by its non-conducting power. When nutriment (especially of an oily character) is absorbed in a quantity more than sufficient for the wants of the system, there is a deposition of the superfluous amount in the form of fat; and this serves as a kind of reservoir of assimilable matter against the time of need. Herbivorous animals, whose food is scanty during the winter, usually exhibit a strong tendency to such an accumulation, during the latter part of the summer; and the store thus laid up is consumed during the winter. Some physiologists regard the fatty matter of the chyle as the chief source of the carbonic acid thrown off by respiration; and consider fat as a store of fuel laid up for the same purpose. In this idea there may be much truth; but there is clear evidence that there must be other sources of the formation of carbonic acid in the tissues; and it is also clear that a part of the fat so laid up, is capable of being converted into the materials for the general nutrition of the body (§ 465).

620. We have to speak of the *Epidermic* tissues, which were long described as altogether inorganic in their character, but which are now known to have the same origin with all the rest. The epidermis consists of a series of flattened scale-like cells, which, when first formed, are spheroidal, but which gradually dry up, their nucleus still remaining visible. These form several layers, of which the deepest can be seen very distinctly to possess the vesicular character, whilst the exterior layers are scaly; and between these, all stages of transformation can be traced. The outer layers are continually being thrown off by desquamation; and new ones are as constantly being formed below, from organizable matter exuded by the true skin. What has been termed the *rete mucosum* is simply the last formed portion of the cuticle; in the Negro, some of the cells bear a pretty strong resemblance to pigment-cells. The epidermic membrane, which is formed by this aggregation of cells, is pierced by the excretory ducts of the sebaceous and sweat-glands, and also by the shafts of the hairs. Its layers become more numerous, as the surface is rubbed; the corium being thus stimulated to an increased exudation. The chemical constitution of this tissue is of peculiar interest in relation to that of the horny appendages which it bears. Recent analysis has shown that the membranous epidermis of the sole of the foot, and the compact horny matter of which nails, horn, wool, and hair are composed, have the same constitution;

the formula of all being 48 C, 39 H, 7 N, 17 O; this bears a close relation to protein, and may be regarded as consisting of one proportional of protein with 1 atom of ammonia, and 3 of oxygen. The epidermis covers the whole exterior of the body, not excepting the cornea. The *nails* may be considered as nothing more than an altered form of epidermis. When near their origin they are found to consist of cells, which gradually dry into scales. A new production is continually taking place in the groove of the skin in which the root is imbedded, and probably also from the whole subjacent surface. It will hereafter be seen that *hair* also originates in the epidermis; the cells of the latter producing fasciculi of fibres within them (§ 635).

621. The internal free surfaces are also covered with a kind of cuticle, to which the name of *epithelium* is given. The existence of an epithelium covering the mucous membrane of the first part of the alimentary canal, has long been known; but it is only of late that any thing analogous to it has been supposed to exist elsewhere. The epithelia are always in contact with fluids, and remain of a soft and pliant nature; they do not undergo exfoliation in the same degree with the cuticle, being less exposed to external influences; but, when the surface is denuded, they are restored in the same manner. The forms presented by the epithelial cells are various. The two chief, however, are found in the *tesselate* or pavement-epithelium, and the *cylinder*-epithelium. The free edges of the cells are sometimes fringed with cilia;* and the epithelium is then said to be *ciliated.* The tesselated epithelium covers the serous and synovial membranes, the lining membrane of the blood-vessels, and the mucous membranes except where the cylinder-epithelium exists. The cells composing it are usually polygonal, and their number of layers small; in many instances there is but a single stratum. A very good example of it will be shown in Fig. 70. The tesselated epithelium which covers the delicate pia mater that lines the cerebral cavities, not even excepting the infundibulum and the aqueduct of Sylvius, supports an abundance of very active cilia, which are attached along the edges of its cells.—The cells of the cylinder-epithelium have the form of long cylinders, or rather truncated cones, arranged side by side, having one extremity free, and the other seated upon the subjacent membrane; frequently these cylinders seem to arise, by a stalk-like prolongation, from a tesselate epithelium beneath. Sometimes each cylinder is formed from more than one cell; as may be distinguished by the number of nuclei which they contain. Various transitional forms may be detected at the points at which the cylinder and pavement-epithelia pass into one another; the tesselated scales appearing to rise more and more from the surface, until they project as pedunculated cells. The cylinder-epithelium is found in the intestinal canal, beyond the cardiac orifice; in the larger ducts of the salivary glands; in the ductus communis choledochus; in the prostate, Cowper's glands, vesiculæ seminales, vas deferens, tubuli seminiferi, and urethra. In all these situations it is continuous with the tesselate epithelium; the latter lines the more delicate canals of the various glands. The cylinders are often fringed with cilia at their extremities; and the motions of these are towards the natural outlets of the cavities or canals they cover. Such an epithelium is found lining the nasal cavities, the frontal sinuses, maxillary antra, lachrymal ducts and sac, the posterior surface of the pendulous velum of the palate and fauces, the Eustachian

* See Art. *Cilia* in Cyclop. of Anat. and Phys. and Princ. of Gen. and Comp. Phys., § 146.

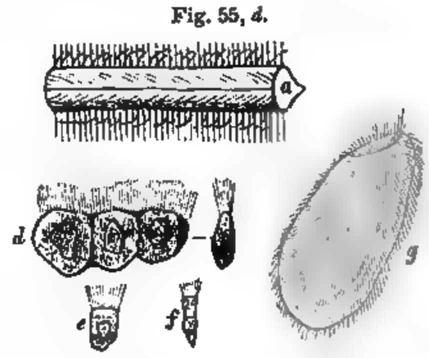
tube, the larynx, trachea, and bronchi, to the finest divisions of these last (where it becomes tesselate, but still ciliated), the upper portion of the vagina, the uterus, and the Fallopian tubes. The function of the cilia is probably to propel the viscid secretions, that would otherwise accumulate on these membranes, towards the exterior orifices from which they may be removed.

{The following clear and excellent description of cilia, by Dr. Todd and Mr. Bowman, the Editor has been induced to introduce in this place, to supply the deficiency in the text.

Certain surfaces, which are, in their natural and healthy state, lubricated by fluid, are covered with a multitude of hair-like processes, of extreme delicacy of structure and minuteness of size. These are called *cilia*, from *cilium*, an eye-lash. They are generally conical in shape, being attached by their bases to the epithelium that covers the surface on which they play, and tapering gradually to a point; or, as Purkinje and Valentin state, they are more or less flattened processes, of which the free extremities are rounded; and this latter form prevails in the human subject. They vary in length from the $\frac{1}{1000}$ to the $\frac{1}{15000}$ of an inch. They are disposed in rows, and are adapted in their arrangement to the shape and extent of the surface to which they belong; they adhere to the edges, or to a portion of the surface, of the particles of the epithelium, preferring the columnar variety of them.

During life, and for a certain period after death, these filaments exhibit a remarkable movement, of a fanning or a lashing kind, so that each cilium bends rapidly in one direction, and returns again to the quiescent state. The motion, when viewed under a high magnifying power, is singularly beautiful, presenting an appearance somewhat resembling that of a field of corn agitated by a steady breeze. Any minute objects coming in contact with the free extremities of the cilia are hurried rapidly along in the direction of the predominant movement; one or more blood-discs, accidentally present, will sometimes pass rapidly across the field, propelled in this way, and very minute particles of powdered charcoal may be conveniently used to exhibit this phenomenon, and to indicate the direction of the movement. The action of the cilia produces a current in the surrounding fluid, the direction of which is shown by the course which the propelled particles take.

Fig. 55, *d.*



Examples of Cilia:—*a.* Portion of a bar of the gill of the Sea-mussel, *Mytilus edulis*, showing cilia at rest and in motion. *d.* Ciliated epithelium particles from the frog's mouth. *e.* Ciliated epithelium particle from inner surface of human membrana tympani. *f* Ditto, ditto: from the human bronchial mucous membrane. *g* *Leucophrys patula*, a polygastric infusory animalcule: to show its surface covered with cilia, and the mouth surrounded by them.

An easy way to observe this phenomenon is to detach by scraping with a knife a few scales of epithelium from the back of the throat of a living frog. These, moistened with water or serum, will continue to exhibit the movement of their adherent cilia for a very considerable time, provided the piece be kept duly moistened. On one occasion we observed a piece

prepared in this way exhibit motion for seventeen hours; and it would probably have continued doing so for a longer time, had not the moisture around it evaporated. However, Purkinje and Valentin have observed it to last for a much longer time than this in connection with the body of the animal. In the turtle, after death by decapitation, they found it lasted, in the mouth, nine days; in the trachea and the lungs, thirteen days; and, in the œsophagus, nineteen days. In frogs, from which the brain had been removed, it lasted from four to five days. The longest time they observed it to continue in man and mammalia was two days; but in general it did not last nearly so long. What appears to be immediately necessary to the continuation of the movement, is the integrity of the epithelial cells to which the cilia adhere; for as soon as these shrink up for want of moisture, or become physically altered by chemical reagents or by the progress of putrefaction, the cilia immediately cease to play.

From these facts we learn two important points in connection with this phenomenon. The first is, the truly molecular character of the movement. Whatever be the immediate cause of the action of the cilia, it is evidently intimately connected with the minute epithelial particles to which they are attached; for cilia never exist in man and the higher animals without epithelial particles, and these particles have no organic connection with the subjacent textures, excepting such as may arise from simple adhesion. And, secondly, we perceive, that this movement is independent of both the vascular and the nervous systems, for it will continue to manifest itself for many hours in a single particle isolated from the rest of the system. After death it remains longer than the contractility of muscle; a circumstance which, together with the facts just mentioned, indicates that the cilia cannot be moved by little muscles inserted into their bases, as some have supposed. And experiment also shows this independence. If the abdominal aorta be tied, the muscles of the lower extremities will be paralyzed in consequence of their being deprived of their blood; and on removing the ligature, and allowing the blood to flow, the muscles will recover themselves. But a ciliated surface is not affected at all in its movements, though the supply of blood to the subjacent tissues be completely cut off. Again, hydrocyanic acid, opium, strychnine, belladonna, substances which exert a powerful effect on the nervous system, produce no influence upon ciliary motion: in the bodies of animals killed by these poisons, the phenomenon is still conspicuous; and even the local application of them does not hinder it, provided the solutions do not injure the epithelial texture. Shocks of electricity passed through the ciliated parts, do not affect the movement. Lastly, the removal of the brain and spinal cord in frogs, by which all muscular movements are destroyed, does not stop the action of the cilia. This striking fact may likewise be adduced to disprove the supposition, that these movements result from the action of minute muscles; for, although muscles may be excited to contract without nerves, we have no instances in the higher animals in which they habitually act without the interference of the nervous system; nor is it likely that a movement existing over so extended a surface, as that by the cilia, would, if effected by muscles, be independent of nervous influence.

Alterations of temperature affect the ciliary motion, owing, doubtless, to the physical change they induce in the epithelial particles. In warm-blooded animals it ceases on a reduction of the temperature below 43° F. In cold-blooded animals, however, it continues even at 32°. In all, a very high temperature effectually puts a stop to it. It is interesting to notice, that all observers agree in stating, that blood is the best preservative of the

ciliary motion, but the blood of Vertebrata destroys it in the Invertebrata. Bile puts a stop to it, very probably by reason of its thick and viscid nature, and not from any chemical influence.

This phenomenon exists most extensively in the animal kingdom. It has been found in all the vertebrate classes; and in the Invertebrata likewise, with the exception of the crustacea, arachnida, and insects. It is the agent by which the remarkable rotation of the embryo in the ova of Mollusca is effected; and it occurs on the surface of the ova of polypes and sponges. The bodies of some of the Infusoria are covered with cilia, which are apparently employed by them as organs of locomotion, and for the prehension of food (fig. 55, *d*, *g*).

In man, the ciliary motion has been ascertained to exist on several surfaces:—1. On the surface of the ventricles of the brain and on the choroid plexuses. So delicate are the cells of epithelium here, that the slightest mechanical injury destroys them; it is, therefore, very difficult to see the movement. Valentin states that its duration is considerable in these parts, so that it may be seen in subjects used for dissection. 2. On the mucous membrane of the nasal cavities, extending along the roof of the pharynx to its posterior wall, on a level with the atlas, on the upper and posterior part of the soft palate, and in the immediate neighbourhood of the Eustachian tube, extending through the tube itself to the cavity of the tympanum. 3. On the membrane lining the sinuses of the frontal bone, the sphenoid, and the superior maxillary. 4. On the inner surface of the lachrymal sac and lachrymal canal. 5. On the membrane of the larynx, trachea, and bronchial tubes. 6. On the lining membrane of the female organs of generation. It does not exist in the vagina; but it may be traced from the lips of the os uteri, through its cavity, and through the Fallopian tubes to their fimbriated margins.

In nearly all these instances there appears to be a mechanical use for the ciliary movement, namely, to promote the expulsion of the fluid secreted by the surfaces on which the cilia exist. Wherever the direction of the motion has been ascertained, it is that which would be favourable to such a purpose. In the bronchial tubes and trachea, the direction of the motion is towards the larynx, so that the cilia may be regarded as agents of expectoration. In the nose of the rabbit, Dr. Sharpey observed the impulse to be directed forwards, and in the maxillary sinus it appeared to pass towards the back part of the cavity, where its opening is situated. In the Fallopian tube, the direction is stated by Purkinje and Valentin to be from the fimbriated extremity towards the vagina. It seems very probable that ciliary motion exists in the kidney, at the narrow neck of each uriniferous tube, as it passes off from the capsule of the Malpighian body. This has not been actually observed in the human subject. It was discovered, and has been frequently seen in the frog.* The movement is here directed towards the uriniferous tube, and it doubtless is destined to favour the flow of the aqueous portion of the secretion from the capsule of the tube.

In the inferior animals the cilia seem to answer a similar end to that in man. They exist extensively on respiratory surfaces, and in connection with the generative organs; and also, but to a less degree, with the organs of digestion. But in some situations, both in man and in the inferior creatures, it is difficult to determine what functions the ciliary motion can perform. Such are, in man, the ventricles of the brain; and, in the frog,

* Bowman, Phil. Trans., 1842.

the closed cavities of the pericardium and peritoneum. Here there are no excretory orifices, towards which the current might set.

What is the cause of ciliary motion? We have shown it to be independent of the blood and of the nerves, and to resist those depressing causes which usually put a stop to the action of contractile tissue. It requires for its continuance three conditions: a perfect epithelium cell; moisture, not of too great density; and a temperature within certain limits. From Schwann's observations it appears that cells exhibit a power of endosmose; that a chemical change occurs in the fluids in contact with them; and that a movement of their internal granules may be seen under certain circumstances. If ciliated epithelium cells exert an attraction of endosmose upon the surrounding fluid, may not this physical phenomenon afford a clue to determine the cause of the movement?

A very remarkable movement is manifested by certain particles found in the secretion of the testicle, which prevails most extensively throughout the animal series, and is even found among plants. From the regularity of these movements and their resemblance to those of minute animals, a place had been assigned by naturalists to the particles in question, in their zoological classifications, under the name "*Cercariæ seminis*," Spermatozoa, or Spermatic animalcules, and Ehrenberg refers them to the Haustellate Entozoa (§ 734). These particles consist chiefly of a long filament or tail, which is sometimes swollen at one extremity, to form the body of the supposed animalcule. The motions consist in a sculling action of the tail, or a slight lateral vibration of it. In many of its conditions it closely resembles ciliary motion; and its duration after death, or after the separation of the fluid, is pretty much the same as that of the ciliary movements. The particles are extremely minute, even measured in their length; but especially so in thickness. They are, therefore, well adapted to obey those impulses which we have shown to be capable of giving rise to molecular motions.—M. C.}

622. It is interesting to observe that the Epidermoid tissues have the simplest structure of any solid parts in the whole animal body; and that they are the most readily renewed. There appears no limit to their power of reproduction; but, when once formed, they undergo no change, except in the loss of their fluids. Their development and growth depend only upon the exudation of the plastic elements of the blood, in contact on one side with a living surface; whilst their exposure on the other side to the air is a constant source of their death by desiccation, and would thus prevent them, even if they were otherwise able, from passing on to a higher grade of organization. Their function is evidently of a simply protective character. It may be remarked that, as far as yet known, cilia are nowhere found except in connection with epithelium cells.

623. In several of the *Cartilages*, the cellular structure is very obvious, whilst in others it has undergone a transition to the fibrous. In all, however, the early stage of formation appears to be the same. The structure originates in cells analogous to those of which the rest of the fabric is composed; but between these cells a larger quantity than usual of hyaline or intercellular substance is deposited; and the amount of this substance continues increasing simultaneously with the bulk of the cells. The original cells are pushed farther and farther from one another; but new cells arise between them, from cytoblasts which are formed in the hyaline substance. The first cells frequently produce two or more young cells from their nuclei; and thus it is very common to meet with groups of such cells, which are known under the name of cartilage-corpuscles. The varieties in the persistent cartilages

principally depend upon the degree of organization which subsequently takes place in the intercellular substance. If a mass of fibres analogous to those of the fibrous membranes (§ 639) should originate in it, the cartilage presents a more or less fibrous aspect; in some instances the fibrous structure is developed so much, at the expense of the cells, that the latter disappear altogether, and the whole structure becomes fibrous. Sometimes the fibres which are developed are rather analogous to those of the elastic tissue (§ 639); these are disposed around the cells, forming a kind of network in the areolæ of which they lie; and this form of cartilage may be termed the elastic. The cartilages which are destined to become bone differ in structure from all these, but have the same origin; and when partial ossific deposits take place in old age, it is almost invariably in the cellular cartilage that they occur. The cartilaginous septum narium, the cartilages of the alæ and point of the nose, the semilunar cartilages of the eyelids; the cartilages of the larynx (with the exception of the epiglottis), the cartilage of the trachea and its branches, the cartilages of the ribs in man, and the ensiform cartilage of the sternum, retain for the most part their primitive cellular organization. The fibrous structure is seen in all the cartilages which unite the bones by synchondrosis; this is the case in the vertebral column and pelvis, the cartilages of which are destitute of corpuscles, except in and near their centres. In the lower Vertebrata, however, and in the early condition of the higher, the fibrous structure is confined to the exterior, and the whole interior is occupied by the ordinary cartilaginous corpuscles.* The reticular structure is best seen in the epiglottis and in the concha auris: in the former of these, scarcely any trace of cartilage corupscles remains; in the latter, the network disappears by degrees towards the extremity of the concha, and the structure gradually passes into the cellular form.

624. The substance that gives to the cellular cartilages their peculiar character, has received the designation of *chondrin*. It bears much resemblance to ordinary gelatin, but requires longer boiling in water for its solution; the solution fixes on cooling, like that of gelatin, and when it becomes dry by evaporation, it has the appearance of solid glue. Chondrin is not precipitated, however, by tannic acid; on the other hand, it gives precipitates with acetic acid, alum, acetate of lead, and protosulphate of iron, which do not disturb a solution of gelatin. Its chemical constitution chiefly differs from that of gelatin in containing less nitrogen and more hydrogen; its formula (as ascertained by analysis before boiling) is 48 C, 40 H, 6 N, 20 O; and it may thus be regarded as composed of 1 atom of protein with 2 additional atoms of oxygen, and 4 proportionals of water. Chondrin is not obtainable, however, from any of the fibro-cartilages except the cornea; these yield gelatin, on boiling, exactly similar to that of the tendons. The elastic cartilages, after being boiled for several days, yield a small quantity of an extract which does not form a jelly, but which has the other chemical properties of chondrin. The cartilage of bone, before ossification, yields only chondrin; after ossification, however, it affords only gelatin; and it is curious that, even when bony deposits take place in the permanent cartilages, the ossified portion contains ordinary gelatin in the place of chondrin. Many of the cartilages naturally contain a large proportion of mineral matter; this is especially the case with the costal cartilages, fractures in which are generally repaired by osseous substance. The ash left by the calcination of these contains a large proportion of the carbonate and sulphate of soda, together with carbonate of lime and a small proportion of phosphate; as age advances, the phosphate of lime predominates, and the soluble compounds diminish. The

* See Mr. Toynbee's Memoir on the Non-Vascular Tissues, Phil. Trans. 1841.

condition of the skeletons of the cartilaginous fishes appears to be nearly allied to this.

625. Like the tissues already described, Cartilage (at least in its simplest form) is nourished without coming into direct relation with the blood through the medium of blood-vessels. From the recent inquiries of Mr. Toynbee,* it appears that the cellular Cartilages are never penetrated by vessels in the healthy state, although in certain diseased conditions they become distinctly vascular. When, however, they are undergoing ossification, large vessels are seen in them; and these vessels remain even when the bone is fully formed. This is well seen in the long bones towards their extremities. At an early period of fœtal life, there is no distinction between the cartilage that is ultimately to become the osseous epiphysis, and that which is to remain as articular cartilage; both are alike cellular, and the vessels that supply them with nutrient materials penetrate no further than their surfaces. At a subsequent period, however, when the ossification of the epiphysal cartilage is about to commence, vessels are prolonged into it; and a distinct line of demarcation is seen betwixt the vascular portion, which is to be converted into bone, and the non-vascular portion, which is to remain as cartilage. At this period the articular cartilage is nourished by a plexus of vessels spread over its free surface, beneath its synovial membrane, as well as by the vessels with which it comes into contact at its attached extremity. Towards the period of birth, however, the sub-synovial vessels gradually recede from the surface of the articular cartilage; and at adult age they have entirely left it, though they still form a band which surrounds its margin. At the same time, the line of demarcation between its attached surface and the subjacent bone becomes more distinct, by the formation of a thin lamella at the surface of the latter, which covers the subjacent cancelli, and is of extremely solid texture, not containing any perceptible foramina through which vessels could pass. The vessels of the cancelli, however, are very large, and have the same dilated or varicose character with those which, at an earlier period, cover the surface of the cartilage. It appears that the articular cartilage is gradually becoming ossified through the whole of life; in old age it is sometimes almost completely converted into bone. From Mr. Toynbee's researches it further appears, that the fibrous cartilages are somewhat vascular; but that the vessels do not extend to the cellular portions, where such exist. No vessels can be traced (according to Mr. T.) into the substance of the true cornea, which, contrary to the statement of Müller, is a cellular rather than a fibrous cartilage. The cells are not so numerous as those of the articular cartilages; and they are surrounded by a plexus of bright fibres, laxly connected together, so as to resemble cellular tissue. Two sets of vessels, a superficial and a deep-seated, surround the margin of the cornea. The arteries of the former are prolonged for a short distance upon the conjunctival membrane, which forms the outer lamina of the cornea; but they terminate in veins at from $\frac{1}{8}$ to $\frac{1}{2}$ a line from its margin. The deep-seated vessels belong to the cornea proper; but they do not enter it, the arteries terminating in veins just where the tissue of the sclerotic becomes continuous with that of the cornea. In diseased conditions of the cornea (as of the articular cartilages) both sets of vessels extend themselves through it; the superficial not unfrequently form a dark band of considerable breadth round its margin; whilst the deep-seated are prolonged into its entire substance. Notwithstanding the absence of vessels in the healthy condition of this structure, incised wounds commonly heal very readily, as is well seen after the opera-

* Phil. Trans. 1841.

tion of extraction of cataract; but the foregoing details make evident the importance of not carrying the incision further round than is necessary, since the corneal tissue should not be cut off from the supply of nourishment afforded by the vessels in its immediate proximity.

626. In connection with the cornea, it is natural to allude to the Crystalline lens and vitreous humour, which have a structure essentially the same. The structure of the crystalline lens has long been known to be fibrous; and Sir D. Brewster has shown, by the aid of polarized light, the very beautiful manner in which the fibres are arranged.* They are united into laminæ, by means of numerous teeth or sinuosities at their edges, which lock into one another. That these fibres originate in cells has been clearly ascertained; but the nature of the metamorphosis has been differently stated by two eminent observers, Schwann and Barry. By the former, the fibres are considered to be prolonged cells: whilst the latter regard them as rather formed upon the plan of the tubes of muscular fibre (§ 374), several cells coalescing into one; in this he is supported by Mr. Toynbee, who states that he has frequently seen the fibres, towards the margin of the lens, made up of such cells. It is considered by Dr. B. that the formation of the crystalline lens affords one of the best examples of the conversion of blood-corpuscles into organized tissue. After it is fully formed, however, it is not permeated by blood-vessels; these being confined to the capsule. During the early part of fœtal life, and in inflammatory conditions of this membrane, both the anterior and posterior portions of the capsule are distinctly vascular; but at a later period, according to Mr. Toynbee, the posterior half only of the capsule has vessels distributed over its surface; and these are derived from the arteria centralis retinæ. From optical experiments which have been suggested to him by this circumstance, he infers that. "objects (radiating lines for instance) situated on the *anterior* surface of the crystalline lens, produce an indistinctness in the image which is formed upon the retina; whereas, when these lines exist upon the *posterior* surface of the lens, the image is clear." The substance of the lens contains about 42 per cent. of animal matter, with 58 parts of water. Nearly the whole of the former may be dissolved in cold water by trituration; the solution is coagulated by heat, and forms a granular but not a coherent mass; alcohol and acids produce the same effect. Hence it appears that the lens chiefly consists of albumen in its soluble form; and this may be supposed to be contained in the cavities of the cells, as it is in those of the vitreous humour. From the latest analyses, it appears that the substance of the lens corresponds with that modification of albumen which forms the globulin of the blood (§ 575);—a circumstance that gives support to Dr. Barry's doctrine. In the Vitreous humour we have an example of a very loose form of vascular tissue, strongly resembling that which constitutes the entire structure of the Acalephæ (Jelly-fish). That the cells composing it have no open communication with each other, is evident from the fact that, when the general enveloping membrane is punctured in several places, it is long before the contained fluid entirely drains away. This fluid is analogous to that of the Aqueous humour, being little else than water holding a small quantity of albumen and saline water in solution. From Mr. Toynbee's inquiries it would appear, that the vessels which pass through the vitreous humour do not send branches into its substance; but that it is nourished by the vessels which are minutely distributed upon its general envelope. The ciliary processes of the choroid membrane are

* Philosophical Transactions, 1833.

almost entirely composed of large, plexiform vessels, which allow a great quantity of blood to circulate through them; and these have probably an important share in the nutrition of the vitreous body.

627. In all the tissues hitherto described, the structure retains, more or less completely, its original cellular character; and it is nourished by fluid supplied to it, not by vessels permeating its own substance, but by those of the nearest vascular part, with which, therefore, its surface only can come into relation. In some of these tissues, especially the epidermic, the parts once formed would seem to undergo little or no subsequent vital change, but gradually lose their connection with the living structure, and are at last thrown off and replaced by newly-formed parts. In these, a constant reproduction is taking place; and such tissues, when accidentally destroyed, are rapidly regenerated. This is readily understood, when their very close proximity with an extremely vascular membrane is considered; the exudation from it speedily takes the form of a layer of cells, and new ones are produced below, until the whole thickness of the cuticle or epithelium is renewed. The epidermoid tissues, however, are placed, by their protective function, and their consequent exposure to external agencies, in the very circumstances which render such a regenerating power necessary; in Cartilage, on the other hand, it is not required, and does not exist. The functions of Cartilage are purely mechanical; the consolidation of their texture by internal deposit renders it little disposed to change by spontaneous decay; and it is protected by its toughness and elasticity from those injuries to which softer or more brittle tissues are liable. These very circumstances, however, interfere with the activity of its nutrition. Cells which are choked up with interior deposit do not readily transmit fluid; and it is doubtful whether any interstitial change can take place in the interior of a permanent cartilage, except when it has become vascular by disease. There is no reason to suppose that cartilage once formed undergoes any considerable alteration, except by ossification, through the whole of life; and there seems ground to believe that, when it has been injured by disease or accident, the loss of substance is not repaired by real cartilaginous tissue. On the other hand, the softer tissues of the eye are capable of complete regeneration. Every oculist is aware that a great loss of vitreous humour may take place without permanent injury; and it has been found that even the crystalline lens may be completely regenerated, after it has been entirely removed by extraction.

628. Proceeding now to the vascular tissues, in which the processes of interstitial absorption and renewal are continually taking place, we commence with *Bone* as the one which has the most evident relations to those already described.

{The Editor has preferred inserting here the description of bone in Dr. Todd and Mr. Bowman's recent work, as giving, in his opinion, the best account of the minute anatomy of this tissue he has yet seen.

It appears from the researches of Mr. Tomes, about to be published in the Cyclopædia of Anatomy, that the ultimate structure of the osseous tissue is *granular*. The granules of bone are often very distinctly visible, without any artificial preparation, in the substance of the delicate spiculæ of the cancelli, viewed with a high power, and in various sections of all forms of bone. They may be generally obtained in calcined bone, either by bruising a fragment of it, or by steeping it in dilute muriatic acid: they may also be made very evident by prolonged boiling in a Papin's digester. The granules vary in size from $\frac{1}{6000}$ to $\frac{1}{14000}$ of an inch. In shape they are oval or oblong, and often angular. They cohere firmly together, possibly by the medium of some second substance. In some few instances Mr. Tomes has

met with a very minute network, which seems adapted to receive them in its interstices; but this he considers to require confirmation.

Where bone exists naturally in an exceedingly attenuated form, it may consist of a mere aggregation of these granules, unpenetrated by any perceptible pores. This constitutes the simplest form under which the tissue can present itself.

But all the osseous tissue with which the human anatomist is concerned is of such bulk as to contain the series of pores and cavities already alluded to for the conveyance of fluid from and to its vascular surface. These *pores* always advance into the bone from open orifices on its surface. They soon arrange themselves in sets, each of which, after anastomosing with neighbouring ones, discharges itself into a small cavity or *lacuna*, in which its individual pores coalesce. From the sides of this lacuna other pores pass off to similar cavities in the vicinity, and others proceed from its opposite surface to penetrate still deeper into the tissue. These pour themselves into another lacuna, or divide themselves between two or three, which are connected in like manner by lateral channels. From these again pass others, which pursue an onward course from the surface; and so on until the whole substance of the bone is perforated by them. The pores from the further side of the extreme lacunæ either open on the surface of the bone which they may now have reached, or else take a recurved direction back into the tissue.

When this beautiful system of microscopic pores and cavities was first seen, it was not recognised as such. The lacunæ were imagined to be solid *corpuscles* (a name still commonly applied to them), and the lines radiating from them to be branching threads of the earthy constituent of bone. They may be proved in many ways, however, to be real excavations in the tissue. With a sufficiently high power their opposite walls can be distinctly seen, as well as their hollow interior; but the most conclusive evidence lies in our being able to fill them with fluid. If a dry section of bone, in which they are very apparent, be moistened with oil of turpentine while in the field of the microscope, the course of this penetrating material can be witnessed, as it advances into the tissue. It is seen to run quickly along the pores from the Haversian canals, and from the surface of the specimen, where they have been cut across. Having entered a lacuna, it suddenly extends along the pores radiating from it, and, through these, reaches other lacunæ; rendering the tissue transparent by filling up its vacuities. In parts where air has previously occupied the vacant spaces, and the turpentine cannot displace it, the characteristic appearance of minute bubbles is often present.

The *lacunæ* of osseous tissue, if examined extensively in the vertebrate class, are found of very various shapes: sometimes scarcely to be distinguished from the pores, of which they are simple fusiform dilatations; at other times large and bulky, and forming the point of junction of a great multitude of pores. In the true *dental* substance, which is a kind of bone, the lacunæ are almost entirely deficient, and the pores attain a very singular development, which will be subsequently described.

But though varieties are occasionally met with, yet, in the true bone of man and the mammalia, the lacunæ possess a very constant form; being somewhat oval, and more or less flattened on their opposite surfaces. The two surfaces look respectively to and from the nearest surface of the tissue, and meet in a thin edge. As pores pass off equally from all parts of the lacunæ, it follows that by far the greater number pass to or from the surface of the bone; an arrangement admirably adapted for the transmission of the nutri-

tious fluids. The pores passing from the edge principally serve to connect together those lacunæ that lie at nearly the same distance from the surface.

The lacunæ have an average length of $\frac{1}{1800}$ of an inch, and they are usually about half as wide, and one third as thick. The diameter of the pores is from $\frac{1}{20000}$ to $\frac{1}{12000}$ of an inch.

The osseous tissue, thus studded by thousands of flattened lacunæ, which lie for the most part in planes parallel to the surface, has a decided disposition to split up into *laminæ*, following the same direction. This is more evident in the bones of old persons, and may be generally promoted by maceration in dilute acid. It is most apparent where the mass of material between two vascular surfaces is great, and the series of lacunæ numerous. It is probable that lamellated structure depends in part on the mode of development and growth of this tissue, and it perhaps contributes to the perfection of the nutritive process within it.

It will now be easy to comprehend the apparently complex arrangement of the osseous tissue in the interior of bones. Let us take, for example, one of the long bones. The entire vascular surface consists of, 1, the *outer surface*, covered by the periosteum; 2, the *inner surface*, lined by the membrane of the medullary cavity, and of the cancelli; 3, the *Haversian surface*, or that forming the canals of the compact tissue, and having in contact with it the vascular network that occupies them, and which has been already described. These involutions of the surface are so arranged that no part of the osseous tissue is in general at a greater distance than $\frac{1}{110}$ of an inch from the vessels that ramify upon them.

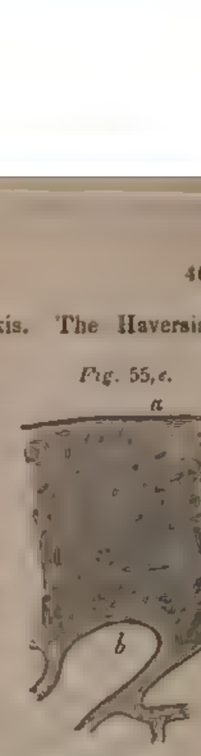
There is a layer of tissue on the exterior of the bone deriving its nourishment from the periosteum, and which may be called the *periosteal layer*. The lacunæ of this layer all face that surface, and the pores of the superficial ones open upon it. There is another layer, forming the immediate wall of the medullary cavity, and termed the *medullary layer*. Its lacunæ, in like manner, face this cavity; and the pores of the inner ones open upon it. This layer becomes variously folded to form the plates and fibres of the cancelli; and all the lacunæ of these face these irregular cavities, and their pores open into them. The Haversian surface, too, being an involution of the outer and inner surfaces, and serving to connect them, is, in fact, formed by an involution of the periosteal and medullary layers, and unites these with one another. Where a vessel enters the compact tissue from the exterior, it carries with it a sheath of bone from the periosteal layer. The lacunæ of this osseus sheath, instead of being turned outwards, like those of the periosteal layer, preserve their relation to the vascular surface to which they pertain, and face *inwards* towards the vessel. Wherever the vessel penetrates, whatever direction it takes, and however it branches, it is everywhere accompanied by this sheath from the periosteal layer, or by offsets from it; and, when it enters the medullary canal, its sheath expands into the medullary layer.

The vessels of the compact tissue are so close together that the osseous sheaths respectively surrounding them come into contact and unite; and thus all the space between the outer and the inner surface of the compact tissue is filled up; thus, in a word, the compact tissue is constructed.

As the vessels of the compact tissue take a longitudinal direction, a transverse section of the bone will appear pierced by numerous holes, which are the Haversian canals cut across. Each hole appears as the centre of a roundish area, which is the section of an involuted periosteal layer now be

come a vertical rod, containing a vessel in its axis. The Haversian canals vary considerably in size, and do not maintain a very close relation to the thickness of their respective osseous walls. They are frequently eccentric, owing to their wall bulging more in one direction than another, to fit in between others in the vicinity: for though the rods of bone, containing the vessels, affect the cylindrical form, they often present an oval, or even a very irregular figure, on a section; their close package having modified their form. The periosteal and medullary layers are also well seen on the same section, the latter curving inwards to constitute the walls of the cancelli. These two layers are of very irregular thickness, as the Haversian rods encroach on them unequally.

Fig. 55, *e.*



Transverse section of the compact tissue of a long bone, showing, *a* The periosteal layer. *b* The medullary layer, and the intermediate Haversian systems of lamellæ, each perforated by its H. canal.—Magnified about 15 diameters.

On a further examination of such a section, with a sufficient magnifying power, we observe the lacunæ of the periosteal and medullary layers facing those surfaces, and their pores opening upon them; while the lacunæ of each Haversian layer all face the corresponding canal, and their pores radiate from it. The lacunæ facing the Haversian surface are generally curved concentrically with it. They are more numerous, and their pores more abundant, on the side where there is most osseous substance, and where it consequently extends furthest from the source of nutriment, the Haversian vessel. The reason of the want of proportion between the width of the canals, and the thickness of their respective osseous walls, appears to be this, that the larger canals transmit vessels to other parts, besides containing those which nourish their own layer; while some of them are, no doubt, in a great measure channels for veins.

The outer lacunæ belonging to an Haversian canal sometimes send out pores to anastomose with those of the neighbouring rods; but this seems to happen chiefly where the contiguous rods have just sprung from a common stock. Occasionally, also, lacunæ of irregular shape lie in the interval of two or more rods, and communicate with lacunæ of all of them; but, in general, the outermost pores of the extreme lacunæ droop back on all sides and re-enter the penultimate series of their own rod.

Fig. 55, *f.*

Transverse section of the compact tissue of a tibia from an aged subject, treated with oil, showing the appearance of lamellæ surrounding the Haversian canals. Portions of several systems of lamellæ are seen. The appearance of the lacunæ, when their pores are filled with fluid, is also seen, as well as the radiation from the canals which then remains. From Mr. Tomes.

Owing to this arrangement, there always appears a transparent interval between contiguous rods; the pores and lacunæ not existing there to intercept the passage of the light. This is a remarkable circumstance, and will be illustrated when we come to speak of the development of bone.

The *lamellated* character of bone can be frequently distinguished in the periosteal, medullary, and Haversian layers; and, in general,

wherever several successive series of lacunæ exist. The Haversian rods, however, are remarkably prone to exhibit this appearance, especially under the conditions previously mentioned. Their lamellæ, however, are not concentric, as commonly described. The fissures which disclose them are indeed concentric, but they are always incomplete, never extending completely round the canal; so that the lamellæ run into one another at various points. This results from the fact, that the lacunæ are not arranged in sets equidistant from the centre, but are scattered, as it were, independently of one another, at every possible variety of distance from the canal. The larger concentric cracks, which generally run through the lacunæ, seem to occur where two or three of these happen to lie nearly in the same curve. Bone is very apt to crack in the interval between the rods; and each of these rods is really so distinct from those near it, that it may be designated conveniently, for the purpose of description, as an *Haversian system of lamellæ.*

In a longitudinal section of the compact tissue of a long bone the appearance of lamellation is generally less evident, except where a longitudinal canal happens to lie exactly in the plane of section. When the Haversian canal is a little below the cut surface, it is of course covered by some of its lamellæ, the lacunæ of which directly over it are seen in face, while the lamellæ dipping in on either side, in their course round the canal, present the thin edges of their lacunæ to the observer. In the former part those pores alone are seen that proceed from the edge of the lacunæ; while in the latter those from both surfaces are seen, and of course appear much more numerous.

The description now given of the intimate texture of the compact tissue of long and short bones will apply, in all essential respects, to every other example of the compact tissue; the chief difference consisting in the direction taken by the Haversian canals, which is irregular where the tissue follows an irregular course. In general, however, the canals, with the Haversian rods forming their sheaths, run in the direction in which the tissue needs the greatest strength. Thus, in the long bones it is vertical; and in those flat bones, which have to support weight, it is also more or less vertical; while in those designed to sustain the action of forces of other kinds it is liable to corresponding variety.

So beautifully mechanical is this disposition of the Haversian systems in the compact tissue, that we need not smile at the descriptions of Gagliardi, who, with imperfect means of observation, appears to have been at least faithful in his attempts to delineate nature. The periosteal and medullary layers are true *plates* of bone, and the Haversian systems are true fibres or *pins*, all connected with one another by direct continuity of tissue, and most artfully arranged for the mechanical ends in view; and we cannot sufficiently admire the skill which has caused the means, employed for these ends, to conspire with those which were indispensable for the due nutrition of the tissue.

In the ordinary cancellated texture, each cancellus must be regarded as a little medullary cavity, containing, as it does, medulla and highly vascular medullary membrane. The plates of bone which form its walls consist of lamellæ, among which lacunæ, with their pores, are scattered; and they sometimes, when thick, contain Haversian canals. Usually, however, the pores of these laminæ communicate directly with the cavity of the cancellus to which they belong.

Of the Vessels of Bone.—We now proceed to inquire into the manner in which the nutrition of bone is provided for. A texture containing so much animal matter, and needing a constant supply of inorganic material likewise must necessarily be largely supplied with blood, the common source of the materials of all the tissues.

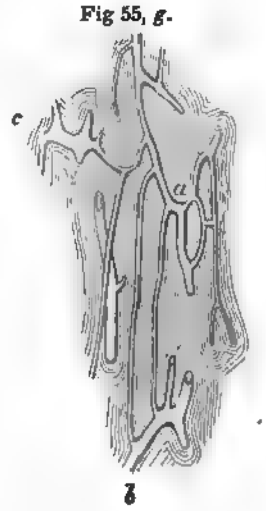
The blood-vessels of bone are very numerous, as may be satisfactorily seen on examining a well-injected specimen. The arteries are in great part continued from those of the periosteum; those which penetrate the cancellated texture of the extremities of the long bones are very large, and ramify freely among the cancelli.

The membrane of the medulla which is contained in the shaft, receives its blood from a special artery that pierces the compact tissue through a distinct canal, known as that for the nutritious artery. This vessel divides into two immediately on entering the medullary canal; of these, one ascends, the other descends, and both break up into a capillary network, anastomosing with the plexuses in the extremities of the bone, derived from the arteries that penetrate there. From the copious vascular network thus formed within the bone, the innermost part of the compact substance of the shaft receives its blood-vessels.

In the compact tissue the arteries pass into very narrow capillary canals, most of which are invisible to the naked eye. In carefully raising the periosteum from a bone that has been subjected to a little maceration, the vessels may be seen in great numbers passing from that membrane into the osseous texture, and many of the larger ones seem to be surrounded by a sheath derived from the periosteum. Similar sheaths may be seen surrounding the vessels of the cancellated texture.

The vascular canals of the compact tissue are styled *Haversian*, after their discoverer, Clopton Havers. They are disseminated pretty uniformly through the tissue, and inosculate everywhere with one another. In the long and short bones they follow the same general direction as the axis of the bone, and are joined at intervals by cross branches. The meshes thus formed are more or less oblong (fig. 55, *g*). The deeper ones open into the contiguous cancelli, with the cavities of which they are continuous.

Fig 55, *g*.



Haversian canals, seen on a longitudinal section of the compact tissue of the shaft of one of the long bones:—*a*. Arterial canal. *b*. Venous canal. *c*. Dilatation of another venous canal.

The arteries and veins of bone usually occupy distinct Haversian canals. Of these the venous are the larger, and commonly present, at irregular intervals, and especially where two or more branches meet, pouch-like dilatations, calculated to serve as reservoirs for the blood, and to delay its escape from the tissue. In many of the large bones, particularly in the flat and irregular ones, the veins are exceedingly capacious, and occupy a series of tortuous canals of remarkable size and very characteristic appearance. These are well described by Breschet in his elaborate work on the venous system. These canals run, for the most part, in the cancellated structure of the bones, and are lined by a more or less complete layer of compact tissue, which itself often contains minute Haversian canals. The veins they contain discharge themselves separately on the surface.—The Haversian canals vary in diameter from $\frac{1}{2500}$ to the $\frac{1}{200}$ of an inch, or more, the average being about $\frac{1}{500}$. Their ordinary distance from one another is about $\frac{1}{120}$ of an inch. They may be regarded as involutions of the surface of the bone for the purpose of allowing vessels to come into contact with it in greater abundance. It is evident that the cancelli, and even the great medullary canal

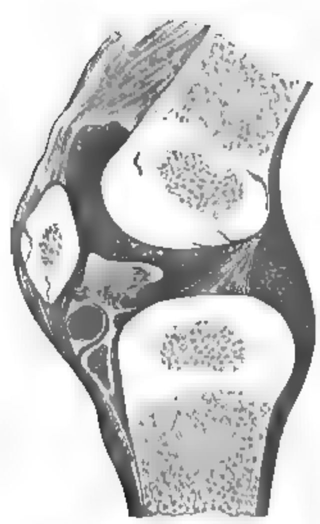
itself, are likewise involutions of the osseous surface, though for a partly different end. These larger and more irregular cavities in bone may be considered as a dilated form of Haversian canals. They contain vessels not only for the nutrition of the thin osseous material forming their walls, but also for the supply of the fat enclosed within them.

Nerves of Bone.—The skill of anatomists has hitherto failed to demonstrate the presence of nerves in the interior of bones. Some nerves pass through bones, but no supply strictly to the osseous matter has yet been proved. Yet there is little doubt that the vascular surface of bones is furnished with nerves: the painfulness of many affections of the periosteum, and of the medullary membrane, seems to place this beyond dispute.

Development.—In the earliest period at which the skeleton can be detected among the other tissues of the embryo, it is found to consist only of a congeries of cells, constituting the simplest form of cartilage. These increase in number and in density, and become surrounded and held together by an intercellular substance in small quantity; thus forming the *temporary cartilage*, which subsequently becomes converted into bone. The temporary cartilages have the same general shape before as after their ossification; and as this process is slow, and not finally completed until adult age, they share during a considerable period in the functions of the bony skeleton.

Until the completion of the process of ossification, the temporary cartilages increase in bulk by an interstitial development of new cells. A few vessels, also, shoot into them at an early period, occupying small tortuous canals, which subsequently become obliterated.

Fig. 55, A.



Vertical section of the knee-joint of an infant; showing the points of ossification in the shaft and epiphysis of the femur and tibia, and in the patella. A few vascular canals are also seen in the cartilage. Natural size.—From the Museum of King's College.

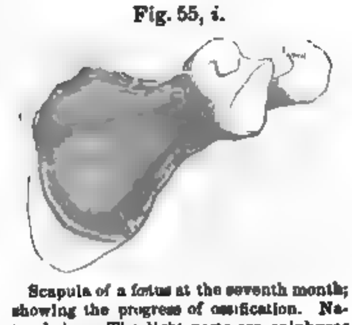
Ossification commences in the interior of the cartilage at determinate points, hence called *points* or *centres of ossification*. From these the process advances into the surrounding substance. The period at which these points appear varies much in the different bones, and in different parts of them. The first is the clavicle, in which the primitive point appears during the fourth week; next is the lower jaw; the ribs, too, appear very early, and are completed early; next the femur, humerus, tibia, and upper jaw. The vertebræ and pelvic bones are late, as well as those of the tarsus and metatarsus. Some bones do not begin to ossify till after birth, as the patella.

In most bones ossification begins at more than one point. Thus, in the long bones (fig. 55, *A*) there is a middle point, to form the future shaft; and one at each extremity, to form the articular surface and eminences. That in the shaft is the first to appear, and the others succeed it at a variable interval. The central part is termed the *diaphysis*, and for a long period after birth there remains a layer of unossified cartilage

between this and the *epiphyses*, as the extremities are then styled. *Processes* of bone have usually their own centres of ossification, and are termed epiphyses until they are finally joined to the main part, after which they receive the name of *apophyses*.

Ossification generally extends in the direction that the future laminæ and Haversian rods are to assume, and which corresponds in a great measure to that in which it is designed that the chief strength of the structure may lie. Thus, in the bones composing the vault of the cranium, there is always a very decided radiation from the most prominent part of the convexity of each. In the scapula this direction is indicated by the lines of shading in the accompanying figure. The outline marks the limits of the temporary cartilage, in which no other points of bone have yet appeared.

Fig. 55, *i.*



Scapula of a fœtus at the seventh month; showing the progress of ossification. Natural size. The light parts are epiphyses as yet cartilaginous.—From the Museum of King's College, London.

The minute history of the process by which temporary cartilage is converted into bone, is of extreme interest. Very good descriptions of it have been given by Sharpey, Miescher, and others; from which, however, it will be seen by the following account that we differ in some important particulars.

The nucleated cells of temporary cartilage are small, and pretty uniformly scattered through a sparing, homogeneous intercellular substance. The nuclei are granular, and large compared with the cells, which are distinguished from the surrounding substance principally by their transparency around each nucleus (fig. 55, *j*, *a*. *a'*).

In the vicinity of the point of ossification, (for example, in one of the long bones,) a sin-

Fig. 55, *j*.

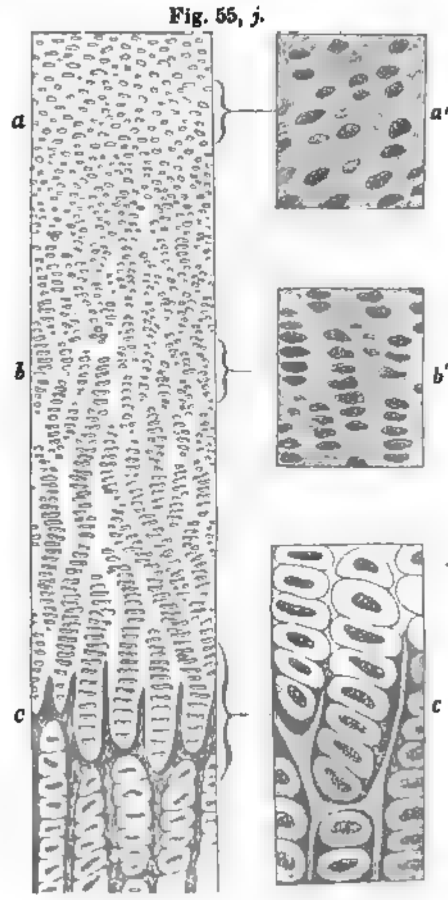


Fig. 55. Vertical section of cartilage near the surface of ossification:—*a*. Ordinary appearance of the temporary cartilage. *a'*. Portion of the same more highly magnified. *b*. The cells beginning to assume the linear direction. *b'*. Portion more magnified. Opposite *c*, the ossification is extending in the intercellular spaces, and the rows of cells are seen resting in the cavities so formed; the nuclei being more separated than above. *c'* Portion of the same more highly magnified.—From a new-born rabbit which had been preserved in spirit.

gular change is observed. The cells are seen to be gradually arranging themselves in linear series, which run down, as it were, towards the ossifying surface. The appearance they present on a vertical section is represented in fig. 55, *j*. At first their aggregation is irregular, and the series small (*b*. *b'*.); but, nearer to the surface of ossification, they form rows of twenty or thirty. These rows are slightly undulated, and are separated from one another by the intercellular substance. The cells composing them are closely applied to one another, and compressed, so that even their nuclei seem in many instances to touch; the nuclei themselves are also flattened, and expanded laterally.

The lowest rows dip into, and rest in deep narrow cups of bone, formed by the osseous transformation of the intercellular substance between the rows. These cups are seen by a vertical section in fig. 55, *j*, *c*. *c'*. As ossification advances between the rows, these cups are of course converted into closed areolæ of bone, the walls of which are lamelliform, and at first extremely thin.

Immediately upon the ossifying surface, the nuclei, which were before closely compressed, separate considerably from one another by the increase of material within the cells. The nuclei likewise often enlarge and become more transparent; a condition first pointed out to us by Mr. Tomes. The changes now enumerated may be conveniently considered to constitute the *first stage* of the process, which extends only to the ossification of the intercellular substance. In this stage there are no blood-vessels directly concerned.

The areolæ or minute *cancelli*, when first formed, contain only the rows of cells which they have enclosed. It is remarkable, that, when the cartilage is torn from the bone, it usually carries with it one or two layers of these cancelli, or a little more than is represented in fig. 55, *j*. If the specimen be examined deeper in the bone, even at a depth of $\frac{1}{10}$ or $\frac{1}{8}$ of an inch, other appearances are met with. The lamellæ of bone enclosing the cancelli are no longer simply homogeneous or finely granular in texture, but have acquired more the aspect of perfect bone. They are also thicker, and include in their substance elongated oval spaces, which, excepting that they are of a roughly granular nature, exactly resemble the *lacunæ* of bone already described. They are evidently the *nuclei* of the cells of the temporary cartilage. They are scattered at pretty uniform distances apart, and they all follow the direction of the lamellæ to which they belong. The curvilinear outline of their now ossified cells can often be partially discerned.

Within the cancelli, only a few cells can be detected, these cavities being chiefly occupied by a quantity of new substance, consisting of granules, and resembling a formative *blastema* or basis, like that out of which all the tissues are evolved. The cells that are met with are in apposition with the wall; and sometimes one of them seems half ossified, and its nucleus about to become a lacuna. The nuclei of these cells have now always the same direction as the neighbouring lacunæ.

It hence appears, that, after the ossification of the intercellular substance, the rows of cartilage-cells arrange themselves on the inner surface of the newly formed cancelli, and become ossified, with the exception of their nuclei, which remain granular, and subsequently form the lacunæ of bone; and that a new substance, or blastema, appears within the cancelli, from which, probably, vessels are developed, and the future steps in the growth of the bone proceed.

The cancelli when first formed are closed cavities. At a subsequent

period they appear to communicate, and thus to form the cancelli and Haversian canals of perfect bone; a complete network of blood-vessels becoming developed within them at the same time.

The subsequent progress of ossification seems to consist essentially of a slow repetition, on the entire vascular surface of the bone, of that process which has been now briefly described. It is probable that new cartilage-cells are developed on that surface, and become ossified in successive layers, their nuclei remaining to form the lacunæ, the uniform dispersion of which through bone is thus explained. The cause of the *lamination* of bone, parallel to its vascular surface, is also thus illustrated.

The first appearance of pores is in the form of irregularities in the margin of the lacunæ. These increase with the consolidation of the tissue, and are converted into branching tubules which communicate with those adjacent. These pores must consequently be formed in the ossified substance of the cartilage-cells. In our account of the lacunæ of perfect bone it was mentioned, that, for the most part, those of contiguous Haversian systems do not communicate across the narrow interval that separates the Haversian rods; this interval having, in fact, no pores. It results from what has just been said of the mode of deposition of new layers, that the primary osseous net-work, formed in the intercellular substance of the temporary cartilage, must come to constitute the substance intervening between the Haversian rods, the non-porosity of which is thus satisfactorily accounted for, as well as the facility with which the rods themselves may be made to separate from one another. As for the lacunæ, their originally granular interior seems to be gradually removed, so that they become vacuities adapted for the conveyance of the nutritious fluids through the compact materials of the perfect bone.

629. *Growth of Bone.*—But it must not be imagined, that, when bone is once deposited in a certain form, it thenceforward permanently maintains its size and shape. Though a lamella be completely ossified, its particles are in constant course of change, during which the most important and extensive alterations of size and figure take place in a slow and gradual manner. Thus the layers first deposited on the inner surface of the early cancelli are pushed out by the succeeding ones, and also acquire a concomitant augmentation of mass; and as, in general terms, the number of lacunæ in bone is proportioned to its amount, the early layers most likely increase by a growth and ossification of cells in their own substance, even for long after they have been pushed away from the vascular surface, and supplanted by the more recent ones. Thus, though bone grows chiefly by layers formed in succession on its vascular surface, yet it also grows in an interstitial manner after being originally deposited. It is in this way only that we can explain the great expansion which the primary intercellular osseous network must undergo, to form that which intervenes between the Haversian systems.

Bone when first formed, then, is disposed as an expanded surface, variously and complexly involuted, and which soon becomes covered with vessels. This is the foundation for its subsequent vascularity, and is the source also of that active power of internal growth, which has been long a theme of admiration with physiologists.

But the expansion of bone once deposited is limited. We before observed that no part of the osseous tissue was at more than a certain minute distance from the vascular surface; and that, if it were so, its nutrition could not be suitably carried on. Now, if more than a certain number of laminæ of new bone were laid down, the earlier ones would be pushed too far from the

supply of blood; and hence the limitation we have spoken of. But it is necessary for bone to grow much more between the commencement of ossification and the adult age than this limitation appears to allow of; and here we come upon an admirable provision to meet this apparent difficulty.

In the *first* place, a most important process of growth is continually going on *in the cartilage*, especially near the ossifying surface, by the multiplication of the cells; and, in the latter situation, by the increase in their dimensions, occasioning that separation of their nuclei, already described. In the long bones this takes place chiefly in the longitudinal direction. which is that in which growth is most active; and it continues till adult age. This fact has been long ascertained, though its real purpose appears to have been overlooked. Hales and Hunter both inserted metallic substances along the shaft of a growing bone, in a young animal, at a certain distance apart; and found, after an interval of time, that the distance between them remained the same, or nearly so, while the extremities of the bone were much further apart; thus proving that the principal growth had taken place near the extremities.

Secondly, bones increase in dimension by an accession of new *osseous* substance on their exterior; this new substance consisting not merely of new laminæ, but of new systems of laminæ, and of new involutions of the vascular surface to form new Haversian canals, so that the earlier systems of laminæ are covered over by the more recent ones. This has been best proved by the experiments with madder.

It was ascertained accidentally by Belchier that the rubia tinctorum, or madder, mixed with the food of pigs, imparted its red colour to their bones; and this circumstance has been ingeniously taken advantage of by several physiologists in the prosecution of researches on the growth of bone.* Duhamel, Hunter, and many others, have performed multiplied experiments of this kind. In the Museum of King's College are some good preparations of bones so acted upon.

It is found that, in very young animals, a single day suffices to colour the entire skeleton, apparently in an uniform manner: in these there is no osseous material far from the vascular surface. But, if we make a transverse section of one of the long bones so treated, we observe the deepest, or even the only colour, to be really on the vascular surface; the Haversian canals are each encircled by a crimson ring. This beautiful illustration is due, as far as we know, to Mr. Tomes, who has long possessed some very elegant specimens prepared in this way.

In full-grown animals the bones are very slowly tinged, because the great mass of the bone is not in contact with blood-vessels; each Haversian system, for example, has only its small innermost lamella in contact with them; and, besides, the osseous matter is altogether more consolidated and less permeable by fluids than at a very early period of life. In the bones of half-grown animals a part of the bone is nearly in the perfect condition, while a part is new and easily coloured. Hence, it is easy in them to distinguish the new from the old by means of madder.

* The colouring of bone by madder results from an affinity of the colouring principle for the phosphate of lime. This opinion was distinctly broached by Haller (El. Phys. t. viii. p. 329), and it was subsequently proved by Rutherford, who showed it experimentally. To an infusion of madder in distilled water add muriate of lime: no change takes place. Then add phosphate of soda in solution. By double elective affinity, phosphate of lime and muriate of soda are formed. The phosphate is insoluble, and subsides in union with the colouring matter as a crimson lake. When madder is given as food, its colouring principle is absorbed, and circulates with the blood; and it colours first that part of the bone which is in course of formation from that fluid, or which has been last formed, *i. e.* which is nearest the vascular surface.

Now, madder given to half-grown animals colours the long bones most deeply in the interval between the shaft and extremeties, and on the surface of the shaft. When madder is given at intervals, the tints in the bone are interrupted; the layers in course of formation during its administration are coloured, while those formed during the intervening periods are colourless. The long period during which bones retain the madder tinge, shows that the colouring matter is not readily resumed by the blood, from its combination with the phosphate of lime; and it seems also to indicate a sluggishness of the nutrient process in bone.

Perhaps few questions have more divided the minds of physiologists than that regarding the share taken by the periosteum in the growth and regeneration of bone; for these last are essentially the same process. We now see that bone does not grow on its exterior because the periosteum is there; and that the only part this membrane takes in the deposit of new bone is by the vascular network mingled with its fibrous tissue, and which does not differ from that on other portions of the osseous surface.

The limited expansibility of the bone already formed is the remote cause to which the growth by new deposit on the exterior is to be referred; and, in this respect, the superficial growth is strictly analogous to the exogenous mode of growth in vegetable structures.

A third mode in which increase of size is provided for, appears to be by the dilatation of the primary cancelli and Haversian canals in the central parts of the bone. In early life the cancelli are small, and there is no medullary cavity. Gradually the cancelli enlarge, and those within the shaft blend more and more with one another, by the removal to a greater or less extent of the intervening osseous walls, until at length a medullary canal is formed, around which the cancelli are very open, large and irregular. The augmentation of the vascular cavities of bone is attended with a development of adipose vesicles and their capillaries in the new space, while the proper vessels of the osseous tissue remain pretty much as before. The fat contained in the medullary canal gradually accumulates so much, that a special artery becomes enlarged to supply it, assuming the very inappropriate title of "*the* nutrient artery of the *bone*." Duhamel placed a ring of silver round the bone of a young pigeon, without injuring the periosteum. After some time, during which the bone had increased in diameter, he found the ring in the medullary canal, which had acquired a capacity equal to the previous diameter of the whole shaft.

This enlargement of the diameter of a long bone by the dilatation of its interior, is attended by two consequences, equally important. The shell of compact tissue is thus adapted to offer greater resistance to injurious mechanical forces, while the disadvantage of a corresponding increase of weight is obviated.—C.]

630. That much cartilaginous tissue remains, even in the fully-formed bone, is evident from the fact that, when the calcareous matter has been dissolved away by the action of an acid, the animal substance which remains has the chemical properties of cartilage, being almost entirely composed of chondrin (§ 624). This, indeed, may be obtained, by long boiling under pressure, from previously unaltered bone; and the calcareous matter is then left almost pure. The lime of bones is for the most part, in the state of phosphate, especially among the higher animals; it is curious, however, that in callus and exostosis, there is a much larger proportion of carbonate of lime, than in the sound bone, in which respect these formations correspond with the bones of the lower animals; but in caries, the quantity of the carbonate is much smaller than usual. The proportion of the earthy

constituents of bones to their organized basis varies much in different p[illegible] of the skeleton, and at different ages. Thus when the scapula contain[illegible] per cent. of bone earth, the temporal bone contains 63½ per cent. Acc[illegible] ing to Schreger,* in the bones of the child, the earthy matter constitutes [illegible] half; in those of an adult it amounts to four-fifths, and in those of a[illegible] person to seven-eighths of the entire mass: this is probably too high [illegible] mate, but it expresses sufficiently well the comparative state of the [illegible] at different periods.† The following is a comparative analysis by Berz[illegible] of the bones of Man and of the Ox.

	Man	Ox.
Cartilage completely soluble in water . .	32·17 }	53·[illegible]
Vessels	1·13 }	
Phosphate of lime	51·04	55·[illegible]
Carbonate of lime	11·30	3·[illegible]
Fluate of lime (Fluoride of calcium) . .	2·00	2·[illegible]
Phosphate of magnesia	1·16	2·[illegible]
Soda, with a small proportion of chloride of sodium	1·20	2·[illegible]
	100·00	100·[illegible]

The composition of the phosphate of lime in bones is peculiar; 8 prop[illegible] tions of the base being united with three of the acid. According to P[illegible] Graham,‡ it is to be regarded as a compound of two tribasic phosph[illegible] namely, $2\,CaO, HO, PO^5 + 2\,(3\,CaO, PO^5)$; with the addition of [illegible] atom of water, which is driven off by calcination. The presence of the [illegible] of calcium in bones has been denied; according to Dr. G. O. Rees's [illegible] inquiries,§ it is by no means uniformly present; it is said, however, to [illegible] in fossil bones; and to be found in considerable quantity in the human b[illegible] disinterred from Herculaneum.

631. The regeneration of Bone, after loss of its substance by disea[illegible] injury, takes place more completely perhaps than that of any other t[illegible] except the fibro-cellular (§ 638). This is partly due to its high degr[illegible] vascularity, and partly to the simplicity of its structure. When we c[illegible] sider the great importance of the mechanical support afforded by bone[illegible] every function of the body, and the necessity for an entire reparation b[illegible] that support can be obtained, we perceive that no half-measures (su[illegible] are adopted in the repair of muscles, ligaments, &c.,) would here su[illegible] The ordinary nutrition of bone takes place through the vessels of the pe[illegible] teum and those of the medullary membrane, from both of which sm[illegible] branches are given off that traverse the Haversian canals; the outer la[illegible] however, are chiefly supplied from the periosteum, and the inner from [illegible] medullary membrane; so that, when the external membrane is destro[illegible] the outer layers die, whilst the inner layers suffer from interruption of [illegible] supply of nutriment received through the lining membrane. In the d[illegible] termed Necrosis, it is seldom (if ever) that the whole thickness of the [illegible] loses its vitality; either the outer or the inner layers suffer; and whic[illegible] part remains alive, it becomes increased in thickness by inflammation [illegible] by the succeeding processes. Plastic lymph is thrown out in la[illegible] this becomes organized, converted into cartilage, and finally into b[illegible] When a bone is fractured, the same kind of process takes place. Org[illegible] able lymph is effused, not only from the vessels of the bone and its [illegible]

* Hildebrandt's Anatomy by Weber, Vol i. p. 316.

† The proportion, however, is by no means constant, as Dr. Davy's experi[illegible] prove. See his Anatomical and Physiological Researches.

‡ Elements of Chemistry, p. 1067.

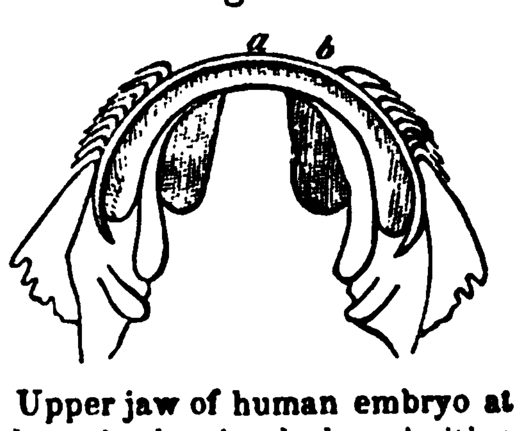
§ Guy's Hospital Reports, Vol. v.

branes, but from those of the surrounding structures; this gradually becomes vascular, and in time assumes a cartilaginiform appearance, although its structure is probably not exactly the same with that of ordinary cartilage. Ossification usually commences at the extremities of the fractured bone; and, if these be near each other, they are soon united by callus. If they be distant, however, their union is a very gradual process. It is not true (as maintained by some) that ossification takes place *only* in the parts where the new substance is connected with old bone. Mr. Gulliver* has remarked that, when the broken portions of bone form an angle, there is quite a distinct centre of ossification, commencing in the soft parts that lie between the sides of the angle. This new bone, being a provision to meet the exigencies of an irregular case, is termed by Mr. G. the *accidental callus;* it forms a support between the fragments, in a situation which is exactly that of the greatest mechanical advantage. Though for some time quite unconnected with the old bone, it soon becomes united to the regular callus. A deposit of osseous matter also takes place occasionally on the interior of the periosteum, when this has been separated from the bone by necrosis of the latter, and by the collection of fluid between them; whether this be true bone, however, has not been ascertained. It is quite certain that in this, as in other cases, the production of the new structure takes place most readily in the parts that are in apposition with the old; but we are not warranted in saying that the presence of the latter is essential. The different membranous structures belonging to the bone contribute to its regeneration, probably in proportion to their vascularity. The bone does not recover its perfect structure for a long period after the callus has become firm; the latter at first commonly fills up the medullary canal; but after a time, cells are formed in it by interstitial absorption, and the canal becomes again continuous.†

632. The *Teeth* are nearly allied to Bone in structure; and in some of the lower Vertebrata, there is no separation between the bone of the jaw and the teeth projecting from it. In Man and the higher animals, however, there is an obvious difference, both in their structure and mode of development. These subjects have lately received much attention; and the practical importance of an acquaintance with them, renders it desirable that they should be here treated somewhat fully. The following account of the early formation of the teeth in the Human fœtus, is derived from the researches of Mr. Goodsir.‡

a. At the sixth week of fœtal life, a deep narrow groove may be perceived, in the upper jaw of the human embryo, between the lip and the rudimentary palate; this is speedily divided into two by a ridge, which afterwards becomes the external alveolar process; and it is in the inner groove that the germs of the teeth subsequently appear. Hence this may be termed the *primitive dental groove.* At about the seventh week, an ovoidal papilla, consisting of a granular substance, makes its appearance on the floor of the groove, near its posterior termination; this papilla is the germ of the anterior superior milk molar tooth. About the eighth week, a similar papilla, which is the germ of the canine tooth, arises in front of this, and during the ninth week the germs of the incisors make their appearance under the same form. During the tenth week, processes from the sides of the dental groove, particularly the external one, approach each other, and finally meet before and behind the papilla of the anterior molar, so as to en-

Fig. 56.

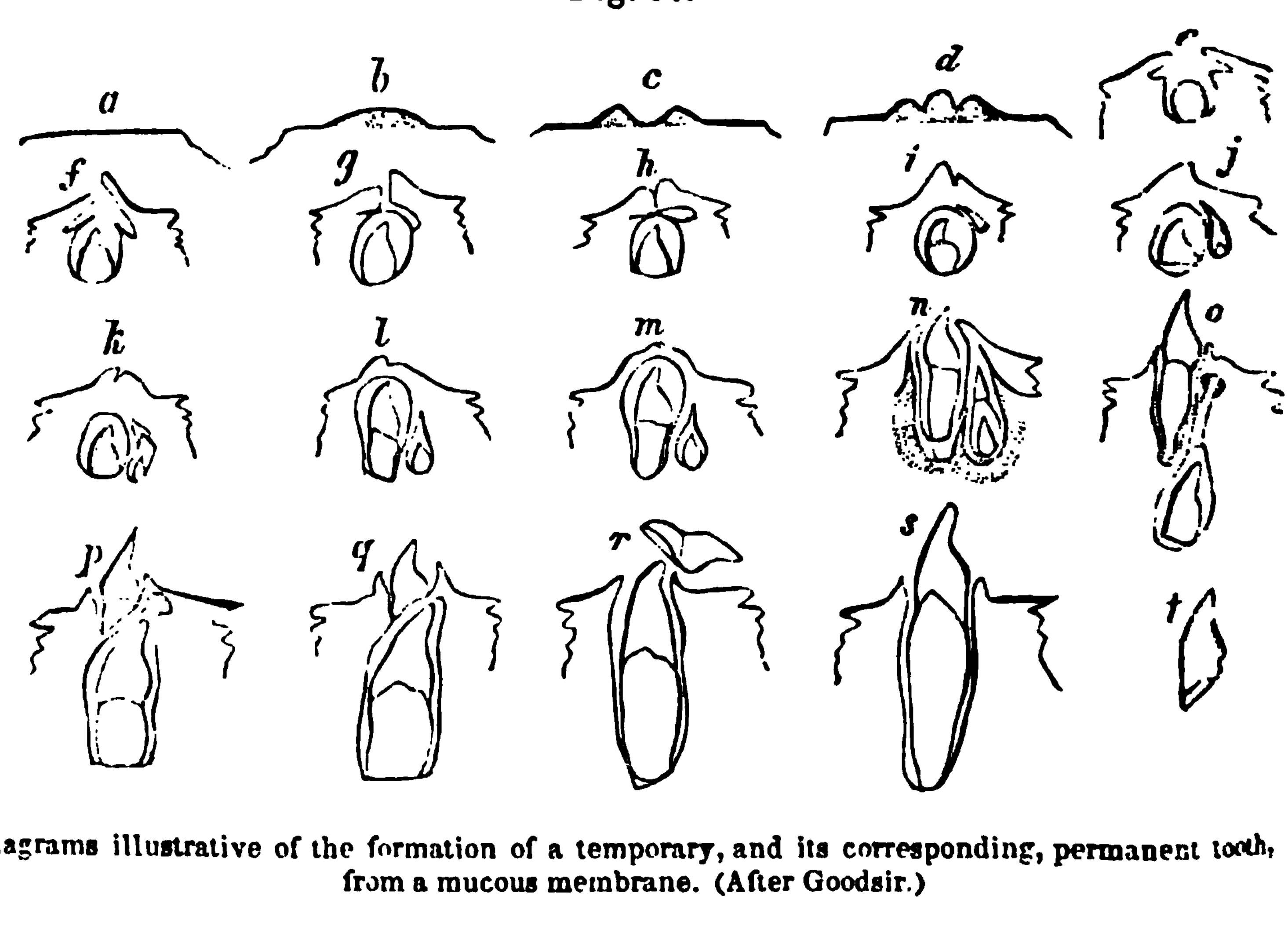


Upper jaw of human embryo at 6th week, showing *b*, the primitive dental groove, behind *a*, the lip. (After Goodsir.)

* Gerber's Anatomy, p. 13, *note;* and Edinb. Med. & Surg. Jour., Vol. XLVI. p. 313.
† A very good account of the different opinions which have been entertained in regard to the reparation of Bone, and of the facts that may be regarded as established, is given by Mr. Gulliver in the Edinb. Med. and Surg. Journal., Vol. XLIV. p. 42.
‡ Edinb. Med. and Surg. Journal, Vol. LI.

close it in a follicle, through the mouth of which it may be seen. By a similar process, the other teeth are gradually enclosed in corresponding follicles. The germ of the posterior milk molar also appears during the tenth week, as a small papilla. By the thirteenth week, the follicle of the posterior molar is completed; and the several papillæ undergo a gradual change of form. Instead of remaining, as hitherto, simple, rounded, blunt masses of granular matter, each of them assumes a particular shape; the incisors acquire in some degree the form of the future teeth; the canines become simple cones; and the molars become cones flattened transversely, somewhat similar to carnivorous molars. During this period, the papillæ grow faster than the follicles; so that the former protrude from the mouth of the latter. At this time, the mouths of the follicles undergo a change, consisting in the development of their edges, so as to form opercula, which correspond in some measure with the shape of the crowns of the future teeth. There are two of these opercula in the incisive follicles, three for the canines, and four or five for the molars. At the fourteenth week the inner lip of the dental groove has increased so much, as to meet and apply itself in a valvular manner to the outer lip or ridge, which has been also increasing. The follicles at this time grow faster than the papillæ, so that the latter recede into the former. The primitive dental groove then contains ten papillæ, enclosed in as many follicles; and thus all necessary provision is made for the production of the first set of teeth. (This series of changes is represented in Fig. 57, *a—g*.) The groove is now situated, however, on a higher level than at first; and it has undergone such a change by the closure of its edges, as to entitle it to the distinctive appellation of ***secondary dental groove***. It is in this secondary groove, that those structures originate, which are destined for the development of the second or permanent set of teeth,—of those at least which replace the milk teeth. This is accomplished in the following manner.

Fig. 57.



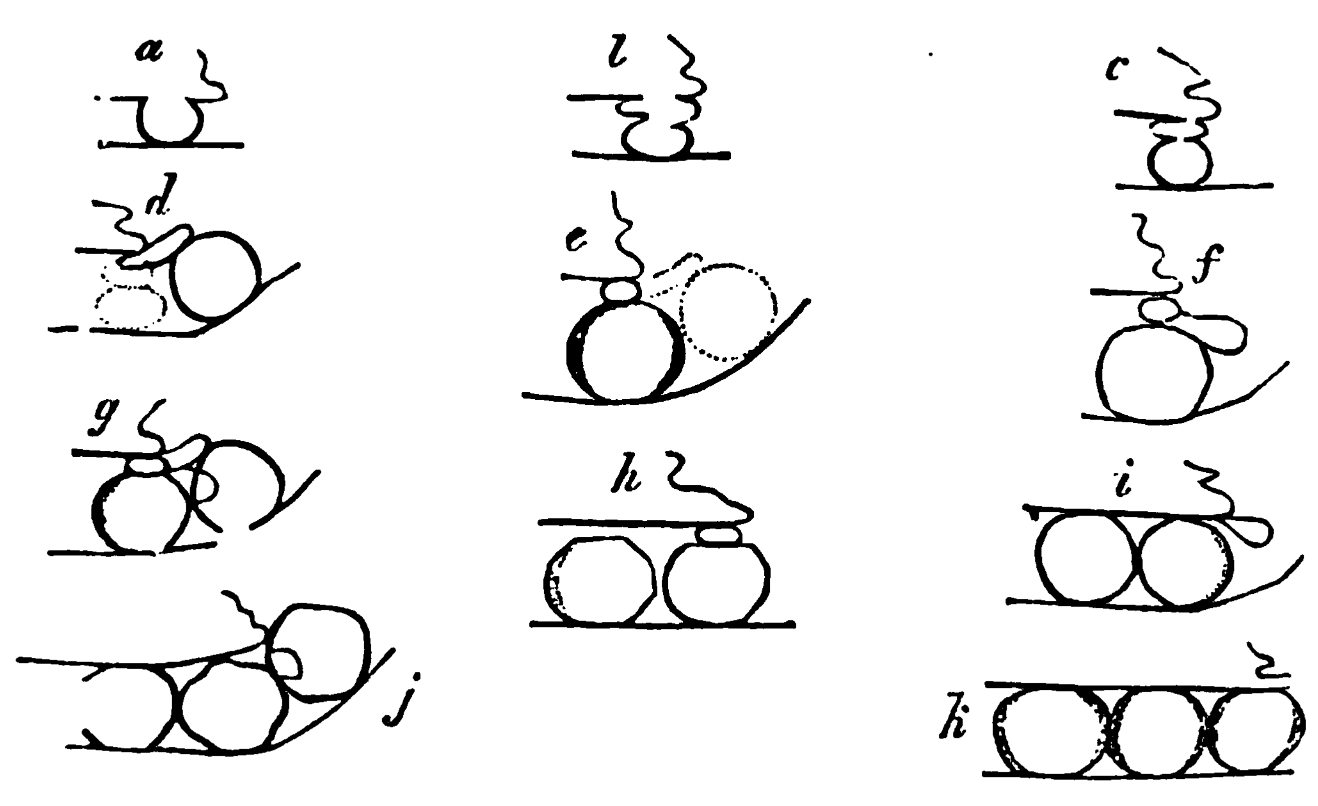
Diagrams illustrative of the formation of a temporary, and its corresponding, permanent tooth, from a mucous membrane. (After Goodsir.)

b. At about the fourteenth or fifteenth week, a little crescentic depression may be observed, immediately behind the inner opercula of each of the milk-tooth follicles. This depression gradually becomes deeper, and constitutes what may be termed a *cavity of reserve*, adapted to furnish delicate mucous membrane for the future formation of the sacs and pulps of the ten anterior permanent teeth. These cavities of reserve are gradually separated from the secondary dental groove, by the adhesion of their edges; and they thus become minute compressed sacs, situated between the surface of the gum and the milk-sacs. They gradually recede, however, from the surface of the gum, so as to be posterior instead of inferior to the milk-sacs; and at last they imbed themselves in the submucous cellular tissue, which has all along constituted the external layer of the milk-sacs. This implantation of the permanent tooth-sacs in the walls of the temporary follicles, gives to the former the appearance of being produced by a gemmiparous process from the latter. This series of changes is represented in Fig. 57, *g—n*.

c. We now return to the milk-teeth, the papillæ of which, from the time that their follicles close, become gradually moulded into their peculiarly human shape. The molar pulps begin to be perforated by three canals, which, proceeding from the surface towards the centre, gradually divide their primary bases into three secondary bases; and these become developed into the fangs of the future teeth. Whilst this is going on, the sacs grow more rapidly than the papillæ, so that there is an intervening space, which is filled with a gelatinous granular substance; this closely applies itself to the surface of the papillæ, but does not adhere to it. The branch of the dental artery which proceeds to each sac, ramifies minutely in its proper membrane, but does not send the smallest twig into the granular substance. At this period, the tubercles and apices of the papillæ or pulps become converted into real *dentine* or tooth-substance, in the manner hereafter stated (§ 633); and the granular matter is absorbed, as fast as this appears; so that, when the process of conversion has reached the base of the pulp, the interior of the dental sac is left in the villous and vascular condition of a true mucous membrane, having upon it a very thin layer of the granular substance, which may be considered as a sort of epithelium; and it is by the deposition of calcareous matter in the fibrous cells of this, that the *enamel* is formed.

d. Whilst these changes are going on, other important preparations are being made for the permanent set. The general adhesion of the edges of the primitive dental groove (§ *a*) does not invade the portion which is situated behind the posterior milk follicle; this retains its original appearance for a fortnight or three weeks longer, and affords a nidus for the development of the papilla and follicle of the anterior permanent molar tooth, which is developed in all respects on the same plan with the milk teeth. After this follicle has closed, the edges of the dental groove meet over its mouth; but as the walls of the groove do not adhere, a considerable cavity is left between the sac of the tooth and the surface of the gum. This cavity is a reserve of delicate mucous membrane, to afford materials for the formation of the second permanent molar, and of the third permanent molar, or wisdom-tooth. The process just described is represented in Fig. 58, *a*—*c*. It will be convenient here to continue the account of the development of these teeth, although it takes place at a much later period. Towards the end of fœtal life, the increase of the bulk of the milk-tooth sacs takes place so much more rapidly than the growth of the jaw, that the sac of the anterior permanent molar is forced backwards and upwards, into the maxillary tuberosity; and thus it not only draws the surface of the gum in the same direction, but lengthens out the great cavity of reserve (Fig. 58, *d*). During the few months which succeed birth, however, the jaw is greatly lengthened; and when the infant is eight or nine months old, the anterior permanent molar resumes its former position in the posterior part of the dental arch: and the great cavity of reserve returns to its original size and situation (*e*). This cavity, however, soon begins to bulge out at its posterior side, and projects itself, as a sac, into the maxillary tuberosity (*f*); a papilla or pulp appears in its fundus; and a process of contraction separates it from the remainder of the cavity of reserve. Thus the formation of the second permanent molar from the first, takes place on precisely the same plan with the formation of the permanent bicuspids from

Fig. 58.



Diagrams illustrative of the formation of the three permanent molar teeth, from the non-adherent portion of the dental groove. (After Goodsir.)

the temporary molars. The new sac at first occupies the maxillary tuberosity (*g*); but the lengthening of the jaw gradually allows it to fall downwards and forwards into the same line and on a level with the rest (*h*). Before it leaves the tuberosity altogether, the posterior extremity of the remainder of the cavity of reserve sends backwards and upwards its last offset—the sac and pulp of the wisdom-tooth (*i*); this speedily occupies the tuberosity after the second molar has left it (*j*); and ultimately, when the jaw lengthens for the last time, at the age of nineteen or twenty, it takes its place at the posterior extremity of the range of the adult teeth (*k*). Thus, the wisdom-teeth are the second products of the posterior or great cavities of reserve; and the final effects of development in the secondary dental groove. In the Elephant, in which there is a continual new production of molar teeth at the back of the jaw, it is probable that from each sac a cavity of reserve is formed, which produces the succeeding tooth; and thus the only essential difference between its dentition and that of Man consists in the degree of continuance of this gemmiparous process, which ceases in Man after being twice performed, but is repeated in the Elephant until nearly the close of its life.

e. We have sketched the history of the development of the teeth, up to the time when they prepare to make their way though the gum. The first stage of this developement may be termed the papillary; and the second, the follicular. The latter terminates when the papillæ are completely hidden by the closure of the mouths of the follicles, and of the groove itself. The succeeding stage, which has long been known as the saccular, is the one during which the whole formation of the tooth substance, and of the enamel, takes place. It is during this period, also, that the ossification of the jaw is taking place; and that the bony sockets are formed for the teeth, by the consolidation of the anterior and posterior ridges bounding the alveolar groove (in which the dental groove was originally imbedded), and of the interfollicular septa which are produced by the meeting of transverse projections from these ridges. The history of development in the lower jaw is very nearly the same; the chief difference being in the origin and situation of the primitive dental groove.

f. We have now only to consider the fourth or eruptive stage,—that in which the teeth make their way through the gum. This process chiefly results from the lengthening of the fang by the addition of new bony matter; and the crown of the tooth is thus made to press against the closed mouth of the sac (Fig. 57, *m*). This at last gives way, so that the sac assumes its previous condition of an open follicle. When the edge of the tooth has once made its way through the gum, it advances more rapidly than can well be accounted for by the usual rate of lengthening of its fang; and this appears to be due to the separation of the bottom of the sac from the fundus of the alveolus; so that the whole tooth apparatus is carried nearer to the surface, leaving a space at the bottom of the alveolar cavity, in which the further lengthening of the root can take place (*n*). The open portion of the sac remains as the narrow portion of the gum, which forms a vascular border and groove round the neck of the perfected tooth (*o*). The deeper portion of the sac adheres to the fang of the tooth, and is converted by ossification into the cementum or crusta petrosa (§ 634). What is commonly denominated the periosteum of the tooth really belongs as much to the alveolus. It is connected with the tooth by the submucous cellular tissue, which originally intervened between the tooth-sac and the walls of the osseous cavity. It appears from Mr. Nasmyth's researches, that the inner layer of the portion of the capsule which covered the crown of the tooth remains adherent to it, forming a thin coating of crusta petrosa (most of which is, however, soon worn off) over the enamel. During the period that the milk-teeth have been advancing, along with their sockets, to their perfect state and ultimate position, the permanent sacs have been receding in an opposite direction, and have with their bony crypts been enlarging; and at last they occupy a position almost exactly below the former (*n* and *o*). They still retain a communication with the gum, however; the channel by which they descended not having completely closed up, and the neck of the sac being elongated into a cord which passes through this. The channels may afterward serve as the *itinera dentium* and the cords as *gubernacula;* but it is uncertain whether they really afford any assistance in directing the future rise of the tooth to the surface, the successive stages of which are represented in Fig. 57, *p*—*t*. The sacs of the permanent teeth derive their first vessels from the gums; ultimately they receive their proper dental vessels from the milk sacs; and, as they separate from the latter into their own cells, the newly-formed vessels, conjoining into common trunks, also retire into permanent dental canals, and gradually become the most direct channels for the blood transmitted through the jaw.

g. The following interesting generalizations respecting the development of the teeth, result from Mr. Goodsir's researches. 1. The *milk*-teeth are formed on both sides of either jaw in three divisions,—a molar, a canine, and an incisive; in each of which, dentition proceeds in an independent manner. 2. The dentition of the whole

arch proceeds from behind forwards, the molar division commencing before the canine, and the canine before the incisive. 3. The dentition of each of the divisions proceeds in a contrary direction, the anterior molar appearing before the posterior, the central incisor before the lateral. 4. Two of the subordinate phenomena of nutrition also obey this inverse law, the follicles closing by commencing at the median line and proceeding backwards, and the dental groove disappearing in the same direction. 5. Dentition commences in the upper jaw, and continues in advance during the most important period of its progress. The development of the superior incisors, however, is retarded by a peculiar cause, so that the inferior incisors have the priority in the time of their completion and appearance. 6. The germs of the *permanent* teeth, with the exception of that of the anterior molar, appear in a direction from the median line backwards. 7. The milk-teeth originate, or are developed, from mucous membrane. 8. The permanent teeth, also originating from mucous membrane, are of independent origin, and have no connection with the milk-teeth. 9. A tooth-pulp and its sac must be referred to the same class of organs as the combined papilla and follicle from which a hair or feather is developed.

h. The following is the usual order and period of appearance, of the several pairs of milk-teeth. The four central incisors first present themselves, usually about the seventh month after birth, but frequently much earlier or later: those of the lower jaw appear first. The lateral incisors next show themselves, those of the lower jaw coming through before those of the upper; they usually make their appearance between the seventh and tenth months. After a short interval, the anterior molars present themselves,—generally soon after the commencement of the second year; and these are followed by the canines, which usually protrude themselves between the fourteenth and twentieth months. The posterior molars are the last, and the most uncertain in regard to their time of appearance; this varying from the eighteenth to the thirty-sixth month. In regard to all except the front teeth, there is no settled rule as to the priority of appearance of those in the upper or under jaw; sometimes one precedes, and sometimes the other; but in general it may be stated, that, whenever one makes its appearance, the other cannot be far off. The same holds good in regard to the two sides, in which development does not always proceed exactly pari passu. The period of dentition is one of considerable risk to the infant's life. The pressure upon the nerves of the gum, which necessarily precedes the opening of the sac and the eruption of the tooth, is a fruitful source of irritation, producing disorder of the whole system, especially of the digestive organs, and not unfrequently giving origin to fatal convulsive affections. These last have been particularly studied by Dr. M. Hall; who recommends the free use of the gum-lancet as a most important means of prevention and cure. Even where dentition proceeds quite naturally, and is not itself a cause of diseased action, it induces an irritable state of the whole constitution, which aggravates the effects of other morbific causes. It is, therefore, of the greatest consequence that the infant should be withdrawn, during this period, from all injurious influences; and that no irregularity of diet, or deficiency of fresh air and exercise, should operate to its disadvantage.

i. After the lapse of a few years, the further elongation of the jaw permits the appearance of the first true molar, which, as already remarked, is really a milk-tooth, so far as its formation is concerned. This commonly presents itself about the middle or end of the seventh year; sometimes preceding, and sometimes following, the exchange of the central incisors, which takes place about the same time. When the permanent teeth have so much enlarged, that they can no longer be contained within their own alveoli, they press upon the anterior parietes of those cavities, and cause their absorption; so that each tooth is allowed to come forwards, in some degree, into the lower part of the socket of the corresponding temporary tooth. The root of the temporary tooth now begins to be absorbed, generally at the part nearest its successor; and this absorption proceeds as the new tooth advances, until the root of the milk-tooth is completely removed, when its crown falls off, leaving room for the permanent tooth to supply its place (Fig. 57, *p*—*t*). This absorption is usually regarded as due to the pressure of the permanent tooth; but this does not appear to be the case; for it is mentioned by Mr. Bell that it is not an uncommon occurrence for the root of the temporary tooth to be wholly absorbed, and for the crown to fall out spontaneously, long before the succeeding tooth has approached the vacant space. The same has been remarked by Mr. Bell, of the cavity in the jaw which is formed for the reception of the sac of the permanent tooth, at the time that it buds off from that of the milk-tooth;—the excavation being often seen to commence before the new sac is formed. Hence, although the two processes, growth and absorption, are usually contemporaneous in each instance, they are by no means dependent on each other. Still it would seem that the existence, if not the pressure, of the new tooth is necessary to determine the absorption of the old; for cases are not unfrequent, in which

the temporary teeth retain their situation in the mouth, with considerable firmness, until adult age, the corresponding permanent ones not having been formed.

k. In the successive replacement of the milk-teeth by the permanent set, a very regular order is usually followed. The middle incisors are first shed and renewed, and then the lateral incisors. The anterior milk molars next follow; and these are replaced by the anterior bicuspid teeth. About a year afterwards, the posterior milk molars are shed, and replaced in like manner, by bicuspid teeth. The canines are the last of the milk-teeth to be exchanged; the development of the new ones not taking place until the 12th year. In the succeeding year, the second pair of true molars appears; the third pair, or *dentes sapientiæ*, are seldom developed until three or four years subsequently, and often much longer. It has been recently proposed* (and, from the evidence adduced in its favour, the proposition would seem entitled to considerable attention) to adopt the successive stages in the second dentition, as standards for estimating the physical capabilities of children, especially in regard to those two periods which the Factory Laws render it of the greatest importance to determine,—namely, the ages of *nine* and *thirteen* years. Previously to the former, a child is not permitted to work at all; and up to the latter, it may be only employed during 9 hours a day. The necessities or the cupidity of parents are continually inducing them to misrepresent the ages of their children; and it has been found desirable, therefore, to seek for some test, by which the capability of the child may be determined, without a knowledge of its age. A standard of height has been adopted by the Legislature for this purpose; but upon grounds which, physiologically considered, are very erroneous; since, as is well known, the tallest children are frequently the weakliest. According to Mr. Saunders, the degree of advance of the second dentition may be regarded as a much more correct standard of the degree of general development of the organic frame, and of its physical powers; and it appears from his inquiries that it may be relied on as a guide to the real age, in a large proportion of cases, whilst no serious or injurious mistake can ever arise from its use. It may happen that local or constitutional causes may have slightly retarded the development of the teeth; in which case the age of the individual would rather be underestimated, and no harm could ensue; on the other hand, instances of premature development of the teeth very rarely, if ever occur: so that there is no danger of imputing to a child a capability for exertion which he does not possess, as the test of height is continually doing. Moreover, if such an advance in dentition should occur, it might probably be regarded as indicative of a corresponding advance in the development of the whole organism; so that the real capability would be such as the teeth represent it.

l. The following is Mr. Saunders's statement of the ages at which the permanent teeth respectively appear. The first true molars usually make their appearance towards the end of the seventh year. Occasionally one of them protrudes from the gum at 6, or more frequently at 6½ years of age; but the evolution of the whole of them may be regarded as an almost infallible sign of the child's being 7 years of age. In other instances, however, where the tooth on one side of the mouth is freely developed, it is fair to reckon the two as having emerged from their capsule; since the development of the other must be considered as retarded. This rule only holds good, however, in regard to teeth in the same row; for the development of the teeth in either jaw must not be inferred from that of the corresponding teeth in the other. With this understanding, the results of the application of the following table will probably be very near the truth.

Central Incisors developed at	8 years
Lateral Incisors	9 —
First Bicuspid	10 —
Second Bicuspid	11 —
Cuspidati	12 to 12½
Second Molars	12½ to 14

The following are the results of the application of this test in a large number of cases examined by Mr. Saunders. Of 708 children of nine years old, 530 would have been pronounced by it to be near the completion of their ninth year, having the central and either three or four lateral incisions fully developed. Out of the remaining 178, it would have indicated that 126 were 8½ years old, as they presented one or two of the lateral incisors; and the 52 others would have been pronounced 8 years old, all having three or four of the central incisors. So that the extreme deviation is only 12 months; and this in the inconsiderable proportion (when compared with the results obtained by other means) of 52 in 708, or 7½ per cent. Again, out of 338 chil-

* "The Teeth a Test of Age, considered with reference to the Factory Children." By Edwin Saunders.

dren of 13 years of age, 294 might have been pronounced with confidence to be of that age, having the cuspidati, bicuspid, and second molars, either entirely developed, or with only the deficiency of one or two of either class. Of the 44 others, 36 would have been considered as in their 13th year, having one of the posterior molars developed; and 8 as near the completion of the 12th, having two of the cuspidati, and one or two of the second bicuspid. In all these instances, the error is on the favourable side,—that is, on the side on which it is calculated to prevent injury to the objects of the inquiry; in no instance did this test cause a child to be estimated as older or more fit for labour than it really was.

m. The value of this test, as compared with that of height, is manifested by a striking example adduced by Mr. Saunders. The height of one lad, J. J., aged 8 years and 4 months, was 4 feet and ¾ of an inch; that of another boy, aged 8 years and 7 months, was only 3 feet 7¼ inches. According to the standard of height adopted by the Factory Commissioners (namely 3 feet ten inches) the taller lad would have been judged fit for labour, whilst the shorter would have been rejected. The dentition of the latter, however, was further advanced than that of the former; for he had two of the lateral incisors, whilst the former had only the central; and the determination of their relative physical powers, which would have been thus formed, would have been in complete accordance with the truth. The elder boy, though shorter than the other by 5½ inches, possessed a much greater degree both of corporeal and mental energy; and his pulse was strong and regular, whilst that of the younger lad, who was evidently growing too fast, was small and frequent. An instance even more striking has come under the Author's own observation.

633. The development of the Human Tooth can only be rightly understood, when it is compared with the same process in the inferior animals. Thus in certain Fishes, as the Shark, the tooth is completed without the formation of the matrix ever having proceeded beyond the first or papillary stage, the tooth remaining attached to the mucous membrane only of the mouth. In many other Fishes and in Serpents, the follicular and saccular stages are completed; but the enamel-organ is not developed. It is evident, then, that the papillary pulp alone is concerned in the formation of the real tooth-substance. From the description of Purkinje and Raschkow, it appears that the parenchyma of the papilla is composed of minute spherical cells, the free surface of which is covered by a peculiarly dense, structureless, pellucid membrane; and it is within this, that the formation of the dentine commences. Blood-vessels soon penetrate the granular pulp, form several anastomoses in their course through its substance, and terminate in a rich and delicate network of capillaries, on that part of the surface of the pulp where the dentine has begun to be formed. The granules of the pulp immediately beneath the preformative membrane, have a more elongated form than the rest, and are placed either vertically, or at an acute angle with the membrane. This appears to be a stage of transition towards the structure, which is afterwards characteristic of the dentine; for a large portion of this consists of tubes formed by the aggregation of cells of longitudinal form arranged end to end.* Dentine may be described as composed of an organized animal basis, composed of tubes and of cells, the former predominating in some instances, the latter in others; and of calcareous particles, of which some appear to be deposited in the substance of the animal membrane itself, and others to be contained in a minutely and irregularly granular state in the cavities formed by it. The tubes pass from the unconsolidated portion, or central pulp cavity, towards the circumference; in some animals, however, the central pulp cavity sends off processes or secondary canals, from which the tubes radiate. The tubes sometimes bifurcate at intervals, and occasionally send off lateral branches; in some animals they terminate in cells with

* This account of the origin of the tubes is confirmed by the observations of Mr. Nasmyth; who has observed that, even in the fully-formed tooth, the tubes frequently have a baccated appearance, resembling a string of beads. See his Memoirs on the Development and Structure of the Teeth and Epithelium.

radiating prolongations like the bone corpuscles. Hence the conversion of the vesicular pulp into the animal portion of the dental structure, involves several degrees of change. Some of the cells are elongated, and form tubes by the breaking-down of the partitions between their extremities. In others, the simple globular form is changed into the radiating. And in a large portion, forming the intertubular substance, but little alteration takes place, the original parenchymatous character being here retained. The calcareous deposition appears to line the tubes, sometimes so thickly as almost to obliterate their calibre. Their use is uncertain, except it be to convey this matter from the pulp cavity towards the exterior of the tooth. Dentine is itself entirely destitute of vascularity; but the membrane lining the pulp cavity, and extending into its prolongations (where such exist), is minutely vascular. Its chemical composition is nearly the same with that of bone; but the animal matter is in smaller proportion, not amounting to more than from 20 to 29 per cent.; and the proportion of phosphate to carbonate of lime is greater.

634. The formation of the Enamel has already been described. This substance contains a much larger proportion of the hardening salts than do the other dental tissues; the animal matter forms not more than 2 per cent., whilst the phosphate of lime constitutes 88½ parts in 100. In its most perfect form it is very uniform in structure, consisting of a series of prismatic fibres or elongated cells lying in close proximity to each other, their membranous walls being completely permeated with calcareous matter, as well as lined with the deposit which fills the cavities. Another substance—the Crusta Petrosa or Cementum—still remains to be described; this forms but a small part of the Human tooth; merely surrounding its fang, and originally existing as a very thin layer over its crown; but in the molar teeth of herbivorous animals, it is a very important constituent, forming thick plates between the dentine and the enamel. This substance has very nearly the characteristic structure and composition of true bone; and it appears to be formed by the ossification of the membrane of the sac, the lower part of which, as already explained, closes round the base of the tooth at an early period.* It is thought by Mr. Goodsir that the opercula of the sacs of Human Teeth are rudimentary organs, which assume their full development in the sacs of elephantoid, ruminant, and other compound teeth; where they dip down as depending folds, by the ossification of which, the occurrence of plates of cementum in the midst of these teeth is fully accounted for. It is by an inflammatory process, taking place in the ossified capsule surrounding the fang, that those exostoses are produced, which sometimes form very troublesome appendages to the teeth. Besides these three substances, a fourth has been very recently described by Mr. Nasmyth, as occurring normally in many of the lower animals, and as occasionally presenting itself as a result of diseased action in Man. This is formed by the consolidation of the central part of the pulp, which usually remains uncalcified, occupying the cavity of the tooth; "it partakes much of the fibrous character of the ivory, being composed of irregularly-radiating filaments; blended with small calcigerous cells in which ossified vessels are seen to ramify;" and may be considered, therefore, as intermediate between true ivory and bone.

635. We have now to consider those tissues in which little or no trace remains of the primordial cells; and in which these are replaced by fibres. Much obscurity still hangs over the nature of this metamorphosis; and it

* This and most of the statements contained in §§ 633 and 634, are derived from the Introduction to Prof. Owen's Odontography.

may be advantageous for us to begin by considering it as it presents itself in one of the extra-vascular tissues, which is properly ranked among the epidermoid appendages. The *Hair* takes its origin in little follicles or open sacs, formed by the inversion of the cutis, and lined by a reflexion of the epidermis. Each of these follicles contains what is designated as the *bulb* of the hair, which has generally been described as the soft newly-formed part that subsequently consolidates into the outer portion; whilst the still softer interior of the bulb, termed the pulp, has been supposed to furnish the matter of the interior. The follicle is extremely vascular; and even the bulb is reddened by a minute injection, though no distinct vessels can be traced into it. It has until recently been imagined that the Hair, like the other extra-vascular tissues, is a mere product of secretion; its material (horny matter, § 620) being elaborated from the surface of the pulp. This, however, proves to be a very erroneous account of it. By the recent inquiries of Dr. Bidder* it has been shown, that the hair, like other tissues, has its origin in cells, and is produced by a very simple transformation of them. It appears that the pulp consists of an aggregation of cells, springing from the deepest part of the follicle or capsule; the form of these, towards the lower part, usually approaches the globular, whilst nearer the base of the hair they are more prolonged. The average longest diameter of these cells is about ·000039th of an inch; their nuclei may be occasionally seen, but are very minute. They are united together by a cytoblastema or intercellular substance of considerable tenacity. Nearer the base of the hair, the cells undergo a considerable change of form; their extremities are much prolonged, whilst their breadth is diminished; and they now form connected series, by adhesion to each other, which constitute what are ordinarily known as the root-fibres of the hair. These fibres may be traced continuously into the hair, which is entirely composed of them; they may be seen without difficulty in the newly-formed portion; and even the fully-developed and hardened part may be resolved into a kind of plexus of such fibres, by prolonged maceration in acids. These fibres, again, may be distinguished as consisting of bundles of fibrillæ, which are evidently elongated cells of great minuteness, having, at their broadest part (in which the nucleus may be distinguished) a diameter of only about ·00003th of an inch. These are united by the cytoblastema, to which the the colour of the hair appears due. The number of the fibrillæ which must be united in the diameter of the hair, is estimated at about 250; this is far greater than that of the cells composing the pulp, although the latter is three times the diameter of the hair; and it can scarcely be doubted, therefore, that each fasciculus of fibrillæ is in fact a bundle of secondary cells of an elongated form, developed in the usual manner from the primary cells of the pulp.†

636. The Hair, then, can no longer be regarded as an unorganized secretion, any more than can the epidermis, and its other appendages. This is made very evident by an examination of the quill of the Porcupine, or the spine of the Hedgehog, which are nothing else than hair on a large scale; the interior of these is composed of a sort of medulla, which, when examined with the microscope, is found to consist entirely of distinct vesicles resembling those of the pith of plants; whilst the exterior is formed by a plexus of horny fibres, resembling those which constitute the whole

* Müller's Archiv. 1840, and Edinb. Phil. Journal, July, 1841.

† This is the Author's own explanation of the difficulty suggested by Dr. Bidder; it is perfectly conformable to facts elsewhere ascertained respecting the development of secondary cells. See Princ. of Gen. and Comp. Phys. § 430.

Human hair. The distinction between medullary and cortical substance may be traced in the true hairs of many other animals,—as in the bristles of the Hog; in some, the hair is tubular, with transverse partitions at intervals, like those in the stems of Grasses. It is quite evident that the active growth of the hair can only take place at its base, where alone it is in connection with the vascular system; but the knowledge of its organized structure enables us to explain many phenomena, which were previously obscure. Thus, in the disease termed Plica Polonica, a change takes place in the hair, which often occurs at a distance from its roots; this change consists in the splitting of the hair into fibres, and the exudation from it of a glutinous substance; which two causes unite in occasioning that peculiar *matting* of the hair, which has given origin to the name of the disease. It is said that bleeding takes place, in this disease, from the stumps of hairs which are cut off close to the skin; and this may be easily credited, since the increased activity in the secretive power of the cells of the hair must require an increase in their supply of blood. It is very easy to understand, from the analogy of the Cellular Plants in which no vessels exist, how the fluid that is supplied to the base of the hair may find its way upwards; it will, of course, be more freely transmitted by the newly-formed cells from one to another, than by those of which the interior is lined by horny deposit, as must be the case with the cell-fibres of which the fully-developed hair is composed. But even these are capable of being affected by fluid supplied to the base of the hair; as is evident from the well-known fact of sudden change of colour of the hair under the influence of strong mental emotions. The nature of the colouring matter is not known; it is bleached by chlorine; and its hue seems in part to be influenced by the presence of iron, which is found in larger proportion in dark that in light hair.

637. The following general account of the growth of Hair is, perhaps, the most complete that our present acquaintance with it permits. The cells of the pulp are evidently, in the first instance, a modification of those of the epidermis, being produced in continuity with them from a portion of the surface of the cutis vera. The primary cells become elongated, and generate within themselves fasciculi of fibres or secondary cells, which interlace to form the hair-cylinder. The walls of these fibre-cells are at first soft and permeable; and the lower part of the hair, which is composed of them, seems to admit the passage of fluid without much difficulty. At a short distance from the base, however, the horny character of the hair, occasioned by the deposit of horny matter in the interior of the fibres, becomes apparent. There is, then, at the base, a continual formation of soft fibrous tissue, by which the length of the cylinder is increased; whilst at a short distance above it, there is a continual consolidation of this (as it progressively arrives at that point) by a deposit of a peculiar secretion in its substance.

638. A very large proportion of the body, in the higher Animals, is composed of a tissue to which the name of *Cellular* is ordinarily given; this term, however, is so much more applicable to those structures that are composed of a congeries of distinct cells, and the use of it for both purposes is likely to engender so much confusion, that it is much to be wished that its application to this purpose should be altogether discontinued. The tissue in question is composed of a network of fibres, and of lamellæ formed by the adhesion of fibres laid side by side; and these are interwoven in such a manner, as to leave very numerous interstices and cavities amongst them, having a tolerably free communication with each other. These interstices are filled during life with a serous fluid. It has been proposed to designate

this tissue as *areolar;* but perhaps the term *fibro-cellular* may be regarded as equally distinctive, and may be more readily adopted. That this tissue, like those already described, originates in cells or vesicles, there can be no doubt; and Dr. Barry considers the correspondence between these primordial cells and the blood-corpuscles to be sufficiently evident. It has been stated by some observers that the cells themselves become transformed into fibres, by elongation and by the splitting of their membrane; but it rather appears that the fasciculi of fibres which originate in each cell is in some way produced from the contents of that cell, perhaps in the manner just described in regard to hair. The fibres, when completely formed, are from 1-18000th to 1-13500th of an inch in diameter; they are usually nearly cylindrical, and commonly run in sinuous lines.

Fibro-cellular or *areolar* tissue, when examined under the microscope, is found to be composed of two elements. The one formed of inelastic wavy bands of variable thickness, in which are numerous longitudinal streaks, not usually parallel to the border, however. The tortuous appearance of these streaks disappears on stretching; and they seem more the marks of a longitu-

Fig 55, *k*.

The two elements of Areolar tissue, in their natural relations to one another:—*a*. The white fibrous element, with cell-nuclei, *i*, sparingly visible in it. *b*. The yellow fibrous element, showing the branching or anastomosing character of its fibrillæ. *c*. Fibrillæ of the yellow element, far finer than the rest, but having a similar curly character. *d*. Nucleolated cell-nuclei, often seen apparently loose.—From the areolar tissue under the pectoral muscle, magnified 320 diameters.

Fig. 55, *l*.

Development of the Areolar tissue (white fibrous element):—*e*. Nucleated cells, of a rounded form. *f*, *g*, *h*. The same, elongated in different degrees, and branching. At *h*, the elongated extremities have joined others, and are already assuming a distinctly fibrous character. (After Schwann.)

dinal creasing, than a true separation; for it is impossible to tear them up, by any art, into filaments of determinate size, although they manifest a decided

tendency to tear lengthwise.* The larger of these bands are often as wide as $\frac{1}{300}$th of an inch; they branch and unite with others here and there. The smaller ones are so minute as to be visible only by the highest powers. This is the *white fibrous element*. The *yellow fibrous element* consists of long single, elastic, branched filaments, with a dark, decided border, and which when not stretched are disposed to curl. They are entirely distinct from the other fasciculi merely interlacing with them. They are about the $\frac{1}{8000}$th of an inch in diameter (Fig. 55, *k*). These two elements may be readily distinguished by immersing the tissue in dilute acetic acid, which causes the *white fibrous element* to swell, and become transparent, whilst the other element is not affected. When the wavy bands of the white fibrous part are touched by the acid they expand *en masse* according to Todd and Bowman, not as though constituted of a bundle of fasciculi. Yet there often remains in them an appearance of more or less wavy transverse lines, at pretty equal distances, bearing a remote resemblance to those in the fibre of striped muscle. This appearance has not yet been explained. The acetic acid also brings into view oval corpuscles, sometimes broken into fragments, and stretching for some distance along the interior of the band. These are probably the nuclei of the cells, from which the bands are originally produced. Schwann has described areolar tissue as consisting in its incipient stage, of nucleated particles sending offsets on the opposite sides, and uniting with others in the neighbourhood. The threads thus formed are homogeneous, but their wavy character is subsequently developed among the longitudinal streaks. Todd and Bowman† state that, they have frequently observed among the threads of areolar tissue taken from adult subjects a number of corpuscles (Fig. 55, *l*, *d*.) either isolated, or having very delicate prolongations among the neighbouring threads. They suppose that these are advancing or receding stages of the tissue.—M. C.}

Fibro-cellular tissue is traversed by blood-vessels and lymphatics which are abundantly distributed through it; it is very readily reproduced; and cells and nuclei in all stages of development are met with, when it is fully examined,—showing that it is in process of active growth or renewal in the ordinary condition of the living body. It possesses a considerable amount of elasticity, and some real contractility, which is called into play by certain stimuli. The particular manner in which the fibres are interwoven, varies greatly in the different situations in which this tissue presents itself. The chief proximate principle contained in the cellular tissue of adult animals is gelatin, which is readily dissolved by boiling; it appears, however, that the fibres themselves are not acted on by this process, so that the soluble matter must be of the character of an inorganic deposit. The corresponding tissue of the fœtus, which constitutes a large proportion of its whole fabric, does not yield gelatin by boiling; so that this deposit must take place at a later period. The serous and synovial membranes belong, both structurally and chemically, to the same category with fibro-cellular tissue. The liquid which is ordinarily contained in the areolæ or cellular membrane, appears to be little else than the serum of the blood, in a state of dilution; it is chiefly water, but contains a sensible quantity of common salt and of albumen, and (when concentrated) a trace of alkali sufficient to affect test paper. The liquid secreted from the serous membrane contains as much as 7 or 8 per cent. of albumen and salts; and it is distinctly alkaline, from the presence of carbonate or albuminate of soda. The liquor amnii and the fluid of hyda-

* Physiological Anatomy, Part 1st., p. 74.
† Loc. cit. p. 75.

tids are of the same composition. The fluid contained in the synovial capsules, and of the bursæ mucosæ, may be considered as serum with from 6 to 10 per cent. of additional albumen; it shows an alkaline reaction. The fluid of dropsy (at least in some forms of this disease) contains in addition urea, and cholesterin suspended in fine plates; also (according to Dr. Kane) stearine and elaine.*

639. The yellow tissue of which the middle coat of the arteries, the chordæ vocales, the ligamentum nuchæ, and many other *elastic* parts are composed, differs from fibro-cellular tissue rather in its chemical composition, and in the size of its fibres, than in its essential structure or origin. When fully formed, the fibres are prismatic, frequently four-sided, and have a diameter of from 1-6000th to 1-4500th of an inch; they generally form a tolerably regular network; and they are possessed, individually as well as collectively, of a high degree of elasticity. A piece of true elastic tissue may be drawn out to nearly twice its original length, and will yet contract again to its first dimensions. The permanence of this substance, and of its peculiar property, are very remarkable. It undergoes little change when boiled; and it may be kept almost unaltered for years. From the absence of tendency to spontaneous decay, we might infer that it undergoes but little change in the living body; and this appears to be the case, for it is very sparingly supplied with blood-vessels. The chemical nature of this substance is unknown; for it resists the ordinary agents by which the character of most animal tissues is determined; and it is but little acted on by the gastric fluid. It yields a small quantity of gelatinous matter by long boiling; and this is allied in some of its properties to chondrin. The fibres of *Tendons* are arranged in a different manner from those of elastic tissue, being grouped into straight fasciculi, which usually lie parallel with each other. In tendinous sheaths or aponeuroses, however, the bundles are crossed, in a more intricate arrangement. The origin of these fibres, which are very strong, but are almost destitute of elasticity, is similar to that of fibro-cellular tissue; and their chemical constitution appears to be nearly the same, for they principally consist of gelatin, which requires, however, a longer time for its solution. As in the case of that tissue, the tendons of the fœtus yield little gelatin. Thus, Tendon may be regarded as Fibro-cellular tissue in a state of extreme condensation. Between one form and the other, every variety may be observed, especially in the aponeurotic expansions, which frequently pass at one spot into tendon, and at another into ordinary cellular membrane. Even in the fœtus, the fibres of tendon are less separated by any intervening or connecting matter, than are those of cellular substance; and they come, therefore, more immediately and more closely into contact. Tendons do not possess a high degree of vascularity; and it is doubtful if the true tendinous fibre is ever regenerated. Wounds of tendons are repaired by a substance which is deficient in the shining aspect of the original tissue; and which has more the characters of ordinary condensed fibro-cellular substance. In the *Fibrous Membranes* and *Ligaments*, we have a gradual transition from the form of tissue just described, to fibro-cartilage. Some of the fibrous investments are composed of an intermixture of elastic and tendinous fibres, and have more or less of the peculiar lustre

* Dr. Barry's view of the constitution of the simple fibres of fibro-cellular and other tissues,—that they are formed by the linear arrangement of *discs*, which originate in the nuclei of the parent-cells,—derives confirmation from the analogous observations lately published by Henle in his work on General and Minute Anatomy. This structure has been most distinctly seen by the latter, in the fibrous coat of the arteries.

of the latter; and in many instances, a considerable amount of ordinary fibro-cellular tissue intervenes between the bundles of white fibres which are characteristic of these membranes. The fibrous membranes and ligaments are thus endowed with some degree of elasticity;—a degree much greater than that which is possessed by the tendons. They are less readily acted on by boiling water than are tendons; but the substance they yield has the characters of gelatin. The peculiar contractile fibre which has been mentioned as composing the dartos (§ 400), and as interwoven with the plexus of vessels in erectile organs (§ 519), differs from the round fibres hitherto described, in being of somewhat greater diameter, and in having a redder colour; in these two points it approaches muscular fibre, to which it it also analogous in its properties. Fibres of this character are diffused through the skin; and they are evidently acted on not simply by cold, but by mental emotions, the influence of which can hardly be communicated to them otherwise than through the nervous system.

640. The *Skin* is a very complex texture. Its outer layer, or epidermis, has been already described (§ 620). The true skin or Corium consists of a very intricate plexus of blood-vessels, lymphatics, and sensory nerves, bound up together by elastic and cellulo-fibrous tissue; it also contains in its substance the sebaceous follicles (§ 703), and transmits the ducts of the sweat-glands, which lie beneath it (§ 701). It is very readily regenerated, as might be expected from its conformation. When long boiled, it yields a considerable quantity of gelatin; but this is not so speedily dissolved as that of ordinary cellular and serous membranes. The *Mucous Membranes* seem to be composed of the same structural elements as the skin with which they are continuous; they are modified, however, in accordance with the difference of their functions. The surface of the Mucous membranes is covered with a soft and moist epithelium, instead of with a dry horny epidermis; and their follicles secrete mucus instead of fatty matter. Mucous membranes are the chief instruments of the organic functions. They form the medium through which nutritious matter is introduced into the system; and, by their glandular prolongations, essentially constitute the apparatus of excretion. The sympathies between the cutaneous and muco-membranous systems are of great pathological importance, and will be touched upon hereafter (Chap. XIII.). The mucous membranes, like skin, are readily regenerated. It is remarkable that their chemical constitution should be widely different; the former yield no gelatin by boiling, but seem to contain a large proportion of albumen. The viscid substance which covers the surface of mucous membranes consists of water mixed up with a substance known by the name of Mucus, which constitutes about 5 per cent. of the whole. This substance is insoluble in water, but imbibes it and swells up, so as to form a ropy liquid as if it were dissolved. Its ultimate composition has not been examined; but it appears to bear a very close relation to vegetable mucus or tragacanthine, except that it contains nitrogen, which is not present in the latter. The secretion from the surface of mucous membranes also contains detached epithelium cells, together with granulated globular particles, which are regarded as characteristic of it. That mucus is secreted from the surface of the membrane, and not from its crypts merely, is shown by the fact that it is formed on several membranes in which those crypts do not exist,—such as those lining the frontal and other sinuses of the cranium.

641. The structure of the *Muscular* tissue has been already described in detail (Chap. v.); and it only remains here to add, in regard to its origin and development, that there seems reason to believe that the primitive com-

ponent segments, which are the ultimate elements of the fibrillæ (§ 370), take their origin in the nuclei of the cells, which by their union produce the sarcolemma or investing tube. The solid matter of muscle consists of little else than fibrin, as will be seen from the following analysis by Berzelius. It should be added, however, that it is impossible to separate completely the vessels, nerves, cellular tissue and blood, from the muscular fibre itself; and that the analysis cannot, therefore, be regarded as perfectly accurate in regard to the composition of the essential constituent.

Fibrin	15·80
Cellular substance	1·90
Albumen and hæmatosine	2·20
Alcoholic extract and lactates . . .	1·80
Osmazome(?) and watery extractive .	1·05
Phosphate of lime with albumen . .	·08
Water and loss	77·17
	100·00

Thus something less than 23 per cent. of solid matter exists in ordinary meat; and in 100 parts of this solid matter there are about 7½ parts of fixed salts. Notwithstanding the high vascularity of muscular substance, it is very doubtful whether it is ever regenerated. Wounds of muscles are united by fibro-cellular tissue, which gradually becomes condensed; but the fibres do not possess any degree of contractility.

642. The *Nervous* structure has also been sufficiently dwelt on in the former part of the volume (Chap. III). It may here be added, however, that, according to the most recent observations, the substance contained in the nerve-tubes seems to be fluid during life; and that its granular appearance when examined after death is due to a kind of coagulation. Some appearances have been seen by Valentin, which are considered by him as indicating the existence of a ciliary action within the nerve-tubes; in which case a regular circulation of nervous fluid must be supposed to take place:* the observation, however, requires to be confirmed before it can rank as an ascertained fact. The chemical composition of the brain has occupied much attention; and the following is an outline of the most recent account of it, that of M. Fremy.† In 100 parts of cerebral matter, there exists 80 of water, 7 parts of albumen (or rather fibrin, § 612), and 5 parts of fatty matter.‡ This statement agrees with that of many previous analysts; and it is chiefly with the fatty matter that the attention of chemists has been occupied. This is stated by M. Fremy to contain, besides the ordinary fatty substances, two peculiar acids, termed the cerebric and oleophosphoric. Cerebric acid, when purified, is white, and presents itself in crystalline grains. It contains a small proportion of phosphorus, and differs from the ordinary fatty matter in being partly composed of nitrogen. It is composed of 66·7 per cent. of carbon, 10·6 of hydrogen, 2·3 of nitrogen, 19·5 of oxygen, and 0·9 of phosphorus; and thus, comparing it with the ordinary fatty acids, contains more than twice their proportion of oxygen. Oleophosphoric acid is separated from the former by its solu-

* See Gerber's Anatomy, p. 257.

† Graham's Chemistry, p. 1057. It is there stated that the analytic method of Mr. Conerbe was very defective.

‡ According to Lassaigne, the chemical composition of the cortical and medullary substance is essentially different; the former containing much more water than the latter, and little colourless fat, but nearly 4 per cent. of red fat, which does not exist in the other.

bility in ether; it is of a viscid consistence, but, when boiled for a long time in water or alcohol, it gradually loses its viscidity, and resolves itself into a fluid oil, which is pure oleine, while phosphoric acid remains in the liquor. The proportion of phosphorus which this acid contains is about 2 per cent. Cholesterine (§ 663) has also been extracted from the brain by M. Fremy in considerable quantity. On the whole, the proportion of phosphorus in the brain appears to be about 1 per cent.: a small quantity of sulphur is also present. The proportion of fixed salts is small, being not above 3½ parts in 100 of dry cerebral matter; which is less than half the proportion that exists in muscle. The large proportion of fatty matter contained in the nervous substance, and the increased demand for the nutrient fluid, which evidently takes place when the brain is active, is not improbably one cause why persons of energetic restless minds are usually thin, and why mental tranquillity and repose are conducive to the deposition of fat.

643. From the large amount of blood with which the Nervous System is supplied, and from the tendency of its substance to undergo rapid decomposition, it may be inferred that the nutritive operations are performed in this tissue with great activity; and this appears to be especially the case at the central and peripheral terminations, where the blood-vessels are most intimately connected with it. The regeneration of nervous tissue is performed more completely than that of any other that is so highly organized. The degree to which it takes place has been a question among physiologists; but many facts well known to surgeons prove that it must be complete. For it will scarcely be denied, that the complete recovery of the functions of a nervous trunk or fibre, indicates that the continuity of its component tubes has been restored; since all that we know of the transmission of nervous influence leads to the belief, that such complete continuity is requisite. Now, in the various operations which are practised for the restoration of lost parts, a portion of tissue removed from one spot, is grafted, as it were, upon another; its original attachments are more or less completely severed,—frequently entirely destroyed, and new ones are formed. Now in such a part, as long as its original connections exist, and new ones are not completely formed, the sensation is referred to the spot from which it was taken; but after an interval, during which it frequently loses all sensibility, its power of feeling is restored, and the sensations received through it are referred to the right spot. A more familiar case is the regeneration of skin, containing sensory nerves, which takes place in the well-managed healing of wounds involving loss of substance (§ 602). A more striking example of regeneration of nervous tissue, however, is to be found in those cases (of which there are now several on record) in which portions of the extremities that have been completely severed by accident, have been made to adhere to the stump, and have, in time, completely recovered their natural connection with the circulating, nervous, and other systems. The rapid production of nervous substance in particular cases, is evidenced by Dr. R. Lee's* recent investigations on the nerves of the pregnant uterus. Not only nerves, but ganglia of considerable size, that seem to have no existence under other circumstances, are then apparent.

644. From the foregoing details the obvious inference results,—that each part of the organism has an individual life of its own, whilst contributing to uphold the general life of the entire being. This Life, or state of vital action, depends upon the due performance of the functions of all the subor-

* Proceedings of the Royal Society, June 17, 1841; and Phil. Trans. 1841, Part II.

dinate parts, which are closely connected together. The lowest classes of organized beings are made up of repetitions of the same elements; and each part, therefore, can perform its functions in great degree independently of the rest. But, in ascending the scale, we find that the individual lives of the cells become gradually merged (so to speak) in the general life of the structure; for they gradually become more and more different in function, and therefore more and more dependent on each other for their means of support; so that the activity of all is necessary for the maintenance of any one. Hence the interruption of the function of any important organ is followed by the death of the whole structure; because it interferes with the elaboration, circulation, or purification, of that nutrious fluid, which supplies the pabulum for the growth and reproduction of the individual cells. But *their* lives may be prolonged for a greater or less duration, after the suspension of the regular series of their combined actions; hence it is that *molecular* death is not always an immediate consequence of *somatic* death.* But if the function of the part have no immediate relation to the indispensable actions just adverted to, it may cease without affecting them; so that molecular death may take place to a considerable extent, without somatic death necessarily resulting.

645. The doctrine of development from cells has another important bearing on the philosophy of physiology. It gives us a clearer idea of the nature of the continual processes of decay and renewal, which takes place in the animal body. Every cell has to a certain degree an individual life of its own. This individuality is much more decided in the lower forms of organized being, where each cell can maintain an independent existence, than it is in the higher, in whose fabric a large number having different functions are united into one structure, the combined activity of the whole of which is necessary to the life of any one. But, even in the highest, it is evident that each cell will possess a certain *duration* of its own; and that, from its first period of development, all the changes which it undergoes are governed by laws peculiar to it. In the various parts of the Vegetable, as in those of the Animal, we find a great difference in the duration of the existence of the cells composing them. These differences may be reduced to five heads.

I. Cells may be generated, which have a very transient existence, and which disappear again, without reproducing themselves, or undergoing any transformation. This may be seen in the Vegetable Ovule and in the Germinal Vesicle of the Animal Ovum, as well as in many other parts. In such instances it is obvious that, from their first origin, the cells are subject to a law of *limited duration*, and that their death and decay is as much the result of their inherent constitution, as is that of each entire Animal or Vegetable organism.

II. The contrary extreme to this may be found in those cells, of which the function, instead of being transient, is to be indefinitely prolonged; such are those of which the organs of mechanical support are usually formed. Here the cell, instead of changing its form, or of giving origin to new cells within itself, becomes the subject of an internal deposit of hard matter, which lines its walls, and cuts it off, more or less completely, from the general course of Vital Action. When this is the case, and the hard matter is not itself liable to decomposition, the duration of the cell-walls, which are protected by their peculiar aggregation from exposure to decomposing agents, may undergo little or no change for an almost indefinite period. Thus the

* Cyclop. of Anat. and Phys. Vol. I. Art. *Death*.

heart-wood of Plants, the Bones of Animals, and still more ... Hoofs, Horns, &c. may remain unaltered through a long series ... Of some of these parts it can scarcely be said that they are less ... removed from the organism to which they belonged, than when ... it. In the heart-wood of a Plant, for example, no vital change ... from the time that the woody tubes and cells are once consolidated ... nal deposition; it may decay, whilst still forming part of the ... interfering with its nutritive operations; and if we could possibly ... entirely, without doing injury by the operation to the rest of the ... its absence would be productive of no other evil consequences, than which would necessarily result from the withdrawal of the mechanical ... port afforded by it. The same may be said of the epidermic appendages ... Animals, and of the internal skeletons of the Polypifera, which ... equally unchanged from the time of their first formation. Now as ... these structures hold together, it is evident that the organized parts ... must have undergone little change from the condition in which it ex... the living fabric; and that *their* death takes place, in reality, only wh... structures decay,—this decay being, in fact, the consequence of ... law of existence of such cells, therefore, is that of *indefinitely-pro...* duration; this law must have been impressed upon them from their ... and the power by which their walls secrete and deposit the consoli... materials, appears to be the chief means of keeping it in operation.

III. In all the higher forms of Animal structure, the cells orig... composing it are only the means of generating tissues of other ... in which the Cellular character is less obvious. Thus the Fibrous, ... cular, and Nervous tissues have their origin in cells, which at first ... in no respect different from others, but which subsequently undergo a ... liar metamorphosis, and themselves no longer exist as such. Upon these primordial cells, therefore, a law of *transformation* is impressed ... the time of their first production. In their original aspect, they ... distinguished from the cells which are not destined to undergo any ... metamorphosis; but, just as the first cell of the embryo, from which ... produced, must have some real though not apparent difference from ... which the Polype originates, so must the cell which is afterwards de... into muscular fibre, be inherently different from that which is sub... converted into nervous tissue.

IV. [illegible]

ncy and uniformity in the living body; whilst, on the other hand, it he continual reproduction of new cells in the place of those which lisappeared, that the normal organization is maintained. The limited on of the life of the cells composing the various tissues is further made it, by the rapid disappearanee of the normal organization, and by the f the functional power, of those tissues, when the deficiency of the ed stimuli prevents the development of the new cells, by which alone character can be maintained. Of the change of structure and loss of , which results from disuse and consequent want of nutrition in mus- and nervous tissues, instances have already been given (§§ 221 and

It only remains here to add that there is no reason whatever to be- that the ordinary processes of decomposition and interstitial absorption ore rapid than usual under such circumstances; so that the length of equired for the disappearance of the characteristic structure, and the quent loss of functional power, affords us some idea of the ordinary on of the life of the component cells. It may be stated, then, as a al proposition, that the interstitial change which the whole structure body is, in its normal or physiological condition, continually under- , is due to the regularly-occurring death and reproduction of its com- it cells, of which every one has its own limit of duration.

There is yet another phase under which Cellular life presents itself atural condition in the lower organisms, and in the early condition of gher; but which constitutes a morbid state in the adult condition of tter. This is when cells reproduce themselves with extreme rapidity, ther the primary nor secondary cells undergoing any further transforma- —and the duration of each individual being limited by the develop- of its progeny within it, causing its own distention and final rupture appearance. The growth of the lower Fungi offers a striking example s in the Vegetable kingdom; and the early processes of development ovum of the highest Animals exhibit the same character. Every cell, s generated, proceeds at once to the work of multiplication, for which ns specially destined; and thus it is subject from the first to the law *production.* It is this which distinguishes the fungoid diseases; which the character designated by the Surgeon as *malignancy*, simply from endency to propagation, and his want of power to control it. It seems ble that many other changes of structure are due to a corresponding . The study of the eruptive diseases, more especially, seems likely veil many additional examples of its operation.

i. The duration of the existence of the individual cells in correspond- arts, is subject to some degree of variation, in accordance with the l of life of the entire organism, and with some other circumstances. all the tissues, even those most consolidated, are undergoing con- changes in the young animal, in which the processes of decay and al go on much faster than in the adult, and in the adult than in the person. Even the cells of the bony structure, which in the adult are t permanent, and in the aged person are subject to extremely little e, are liable in the infant to an early decomposition; their places filled up by others, of which the form adapts itself to the growth of ructure. This may be partly accounted for by the imperfect degree ich, so long as the entire organism is undergoing rapid increase, the l structure is developed in any one portion of it; for the degree of idation being less, the tendency to decay will naturally be greater. is explanation is not in itself sufficient; and we must be content at esent to regard it as a general law (which may ultimately prove to

heart-wood of Plants, the Bones of Animals, and still more their Hair, Hoofs, Horns, &c. may remain unaltered through a long series of years. Of some of these parts it can scarcely be said that they are less alive, when removed from the organism to which they belonged, than when included in it. In the heart-wood of a Plant, for example, no vital change takes place, from the time that the woody tubes and cells are once consolidated by internal deposition; it may decay, whilst still forming part of the tree, without interfering with its nutritive operations; and if we could possibly remove it entirely, without doing injury by the operation to the rest of the structure, its absence would be productive of no other evil consequences, than those which would necessarily result from the withdrawal of the mechanical support afforded by it. The same may be said of the epidermic appendages of Animals, and of the internal skeletons of the Polypifera, which remain equally unchanged from the time of their first formation. Now as long as these structures hold together, it is evident that the organized part of them must have undergone little change from the condition in which it existed in the living fabric; and that *their* death takes place, in reality, only when the structures decay,—this decay being, in fact, the consequence of it. The law of existence of such cells, therefore, is that of *indefinitely-prolonged* duration; this law must have been impressed upon them from their origin; and the power by which their walls secrete and deposit the consolidating materials, appears to be the chief means of keeping it in operation.

III. In all the higher forms of Animal structure, the cells originally composing it are only the means of generating tissues of other kinds, in which the Cellular character is less obvious. Thus the Fibrous, Muscular, and Nervous tissues have their origin in cells, which at first appear in no respect different from others, but which subsequently undergo a peculiar metamorphosis, and themselves no longer exist as such. Upon all these primordial cells, therefore, a law of *transformation* is impressed, from the time of their first production. In their original aspect, they cannot be distinguished from the cells which are not destined to undergo any such metamorphosis; but, just as the first cell of the embryo, from which Man is produced, must have some real though not apparent difference from that in which the Polype originates, so must the cell which is afterwards developed into muscular fibre, be inherently different from that which is subsequently converted into nervous tissue.

IV. If, as has been stated to be probable, most or all of these transformed tissues are themselves composed of secondary cells, prolonged into fibrillæ, by the interweaving of which the various tissues are generated, they all come under the same category; and the general laws of cellular existence are as applicable to them as to the more evidently-vesicular tissues. Not being altogether consolidated by internal deposit, but being more or less actively engaged in the performance of vital operations, these cells are intermediate in their character between those classed under the first and second heads. Their duration is probably very limited in some cases, and much prolonged in others. In all instances, however, they have a *definite* period of existence. They are generated, they grow from the alimentary materials with which they are supplied, they arrive at maturity, they decline, they die, and they decay, just as do the isolated vesicles constituting the humblest forms of vegetation. For all of them there is an appointed duration of life, just as there is for the entire Man. Now on this view we can explain many physiological phenomena, which cannot otherwise be very satisfactorily accounted for. It is owing to the continual death and decay of its component cells, that the process of decomposition goes on with such

constancy and uniformity in the living body; whilst, on the other hand, it is by the continual reproduction of new cells in the place of those which have disappeared, that the normal organization is maintained. The limited duration of the life of the cells composing the various tissues is further made evident, by the rapid disappearanee of the normal organization, and by the loss of the functional power, of those tissues, when the deficiency of the required stimuli prevents the development of the new cells, by which alone their character can be maintained. Of the change of structure and loss of power, which results from disuse and consequent want of nutrition in muscular and nervous tissues, instances have already been given (§§ 221 and 382). It only remains here to add that there is no reason whatever to believe, that the ordinary processes of decomposition and interstitial absorption are more rapid than usual under such circumstances; so that the length of time required for the disappearance of the characteristic structure, and the consequent loss of functional power, affords us some idea of the ordinary duration of the life of the component cells. It may be stated, then, as a general proposition, that the interstitial change which the whole structure of the body is, in its normal or physiological condition, continually undergoing, is due to the regularly-occurring death and reproduction of its component cells, of which every one has its own limit of duration.

V. There is yet another phase under which Cellular life presents itself as a natural condition in the lower organisms, and in the early condition of the higher; but which constitutes a morbid state in the adult condition of the latter. This is when cells reproduce themselves with extreme rapidity, —neither the primary nor secondary cells undergoing any further transformation,—and the duration of each individual being limited by the development of its progeny within it, causing its own distention and final rupture or disappearance. The growth of the lower Fungi offers a striking example of this in the Vegetable kingdom; and the early processes of development in the ovum of the highest Animals exhibit the same character. Every cell, as it is generated, proceeds at once to the work of multiplication, for which it seems specially destined; and thus it is subject from the first to the law of *Reproduction*. It is this which distinguishes the fungoid diseases; which derive the character designated by the Surgeon as *malignancy*, simply from their tendency to propagation, and his want of power to control it. It seems probable that many other changes of structure are due to a corresponding cause. The study of the eruptive diseases, more especially, seems likely to unveil many additional examples of its operation.

646. The duration of the existence of the individual cells in corresponding parts, is subject to some degree of variation, in accordance with the period of life of the entire organism, and with some other circumstances. Thus all the tissues, even those most consolidated, are undergoing continual changes in the young animal, in which the processes of decay and renewal go on much faster than in the adult, and in the adult than in the aged person. Even the cells of the bony structure, which in the adult are almost permanent, and in the aged person are subject to extremely little change, are liable in the infant to an early decomposition; their places being filled up by others, of which the form adapts itself to the growth of the structure. This may be partly accounted for by the imperfect degree in which, so long as the entire organism is undergoing rapid increase, the normal structure is developed in any one portion of it; for the degree of consolidation being less, the tendency to decay will naturally be greater. But this explanation is not in itself sufficient; and we must be content for the present to regard it as a general law (which may ultimately prove to be

but a result of some more general principle) that the duration of the existence of individual cells increases, cæteris paribus, with the advance of life. At the same time, their functional activity diminishes. They may be said to live more slowly. The dull perceptions and slow and feeble movements of the aged man, form a striking contrast with the acute sensibility and the rapid and vigorous muscular actions of the child; and the same change may be noticed in the organic functions. Hence it may be stated as a general law, that the vital activity of the cells (and of the parts produced by their transformation) diminishes in proportion to the prolongation of their life; and this law exactly corresponds with what may be observed, in comparing the tissues of different kinds, which are present in the same body. For we uniformly find, that those in which the most active vital changes are going on (such as the nervous and muscular tissues) are those in which the duration of the individual component portions is the least; as is shown by the rapidity of the changes of removal and reposition which are continually taking place in them. The converse holds good also. Further it may be remarked, and this is a matter of much practical importance,—that any thing which increases the functional activity of any particular tissue, thus causing its cells to live faster, diminishes the duration of their lives; as is shown in the increased demand for nourishment, which is set up as a consequence of the continued exercise of the muscular or nervous system, and which, being far greater than can be required for such increase of their amount as results from that exercise, necessarily indicates that a corresponding removal of effete matter, resulting from the death of the cells, has taken place.

CHAPTER XII.

OF SECRETION.

Of Secretion in General.

647. The literal meaning of the term Secretion is *separation;* and this is nearly its true acceptation in Physiology. We have seen that the nutritive materials which are received into the living body, are combined in a certain proportion in the circulating fluid, and that they are carried in its current to every part of the structure. A portion of the elements of the blood,—probably the fibrin and red-particles exclusively,—are being continually separated from it, and introduced into the solid textures, of which they become constituents, forming, as it were, the organized framework, in the interstices of which various other matters (also separated from the blood) are deposited in an inorganic condition. *This* separation, the object of which is to build up a living fabric, has been already considered under the head of Nutrition; but it may be here remarked, that the deposition of calcareous matter in the bones, and of chondrin, gelatin, and albumen in the cartilages and other tissues (if the latter are really, like the former, deposited in an inorganic condition, § 612), is accomplished by a process analogous in all respects to that, by which those other products are separated that are ordinarily considered as Secretions. The same may be said of the serous fluid which distends the areolæ of fibro-cellular tissue, the oily matter contained in the fat-cells, the albuminous fluid of the humours of

the eye, and other analogous constituents of the living fabric. But we have chiefly to consider under the present head, the nature and origin of the products, which are continually being cast forth from the living body; the amount of which is usually, in the adult animal, equal to that of the solids and fluids ingested, after allowance has been made for the portion rejected, in the form of fæces, as indigestible. The experiments of Dr. Dalton* on his own person, give the following as the proportional quantities discharged through the principal channels of excretion. The mean quantity of solid and fluid aliment taken into the system daily (during 14 days in spring) being 91 oz., or about 5¾ lbs., the average amount of fæces (including the solid matter of the bile) was 5 oz.; the average amount of urine was 48½ oz. daily; and as the total weight of the body remained the same, the quantity of fluid and solid matter excreted by the skin and the lungs must have been 37½ oz. At other periods of the year, a variation was observed, especially in the relative amount of fluid passing off by the urine and by cutaneous exhalation.—It can scarcely be questioned, that the chief source of the excretions is to be found in the continued decomposition of the various tissues of the body, which has been several times alluded to (§§ 84 and 645); and it is probable, from considerations heretofore adduced, that they are derived, not so much from the fluid returned into the blood by the lymphatics (as formerly supposed) as from the blood itself (§ 467). During its circulation, it parts with one portion of its constituents in one part of the body,—with another at a different situation,—and so on. It has been seen, from the details already given, that the abstraction of organizable matter does not occasion any chemical change in the constitution of the fluid,—the fibrin and the red corpuscles which are thus removed being continually renewed at the expense of the albumen, whilst of this last a new supply is afforded by the absorbent system. The elaboration of gelatin, however, which is deposited so largely in the solid tissues, must occasion a considerable alteration in the blood; since, in its production from albumen, a certain residuum must be left. This residuum is probably another important source of the products of excretion. In several other instances, peculiarities of action in different parts will deprive the blood that passes through them of its due proportion of certain of its constituents; these are partly restored by its admixture in the heart with the blood that has returned from other parts; but still a general alteration in the character of the blood is the result of its circulation; and for this alteration it is the province of the Excretory function to compensate. A striking illustration may be found in the change of the colour and of the proportional amount of free oxygen and carbonic acid, which takes place in the systemic capillaries, and which is reversed in the passage of the blood through the lungs (§ 520). Particular sources for the respective contents of other excretions will be pointed out, when they are considered in detail.

648. A distinction has already been pointed out (§ 95) between the proper *Excretions*, the retention of which in the blood would be positively injurious, and those Secretions which are destined for particular purposes within the system, and the cessation of which has no immediate influence on any but the function to which they are destined. This distinction is one of great importance, especially when it is considered with reference to the chemical elements that are found in the two classes of fluids respectively. The solid matter dissolved in those of the latter class, is little else than a portion of the constituents of the blood, either pure, or but slightly altered; thus, in the

* Edinburgh New Philosophical Journal, 1832, 1833.

lachrymal fluid, the saliva, the pancreatic juice, the serous fluid of cellular tissue and of serous and synovial membranes, we find little else than albumen and saline matter, derived at once from the blood. The casein, which is the most characteristic ingredient of milk (§ 686), is but a slightly-altered form of albumen; and some curious evidence has recently been obtained, that this alteration commences in the blood and goes on during pregnancy as a preparation for lactation.* On the other hand, the characteristic ingredients of the excretions are very different in character from the normal elements of the blood. They are all of them completely organizable; and they possess, for the most part, a simple atomic constitution. Some of them, also, have a tendency to assume a crystalline form; which is considered by Dr. Pout to indicate their unfitness to enter into the composition of organized tissues. With regard to some of the chief of these, there is sufficient evidence of their existence, in small quantity, in the circulating blood; but it is also clear that they exist there as products of decomposition, and that they are destined to be separated from it as speedily as possible. If their separation is prevented, they accumulate, and communicate to the circulating fluid a positively deleterious character. Of this, we have already seen a striking example in the case of Asphyxia (§ 546); and the two other principal excretions,—that of the Bile and Urine,—will furnish evidence to the same effect. As a general fact, then, it may be stated, that the materials of the Secretions pre-exist in the blood, in a state nearly resembling that in which they are thrown off by the secreting organs; but that the materials of the secretions which are only destined to perform some particular function in the economy, are derived from the substances which are appropriated to its general purposes; whilst those of the excretions are the result of the changes that have taken place in the system, and cannot be retained in it without injury.

649. Of the reason why certain compounds forming part of the circulating blood, are separated from it by one organ, and others by a different one, nothing whatever is known; and there is nothing in the evident structure of these organs that can afford any clue to the attainment of such knowledge. When their ultimate structure is considered, it is found to be neither more nor less than a vascular membrane; made up into various forms for convenience of packing. Of such a membrane, in its most expanded state, that which composes the walls of the serous cavities, or of the synovial capsules, affords a good example; and the fluid which these cavities contain is secreted by it. Of mucous membrane the structure is in some instances almost equally simple; but in general the secreting surface is extended, by the inversion of the membrane into a large number of little open sacs or follicles, which are copiously supplied with blood-vessels, and are equally concerned with the external superficies, in the elaboration of the protective secretion that covers these membranes. In the most complex form of gland, we find nothing but a very obvious modification of this structure. Either the sacs are prolonged into cœca or blind tubes, as is the case in the Human kidney and testis; or they are very greatly multiplied, and are clustered together (just like currants upon a stalk) upon efferent ducts common to several of them, as is seen in the parotid. Now that the particular modification of structure which the gland may present, has no essential connection with the character of the secretion it is destined to form, is evident from this circumstance,—that almost every gland may be found under a variety of forms, in different parts of the animal series. The secreting system, like every other, is far simpler in the lower class of Animals than in the higher; the number of effete

* See Dr. G. Bird, in Guy's Hospital Reports, Vol. v.

compounds to be excreted from the circulating fluid is much smaller; and the variety of purposes for which special secretions are required is much less. Hence, for almost every gland, there is a part of the animal scale below which it does not exist; and when it makes its first appearance, it almost invariably presents a character nearly as simple as that of the least complex glandular structures in the higher animals. Thus the pancreas in Fishes, the mammary-gland in the Ornithoryncus, the salivary glands of the Echinodermata, the urinary organs of Insects, are nothing more than follicles more or less extended, and having separate orifices. Again, in Insects we find that all the glands,—the liver and salivary glands, as well as the kidneys and testes,—have the form of prolonged tubes; whilst in Mollusca, all the secreting organs,—the urinary and genital, as well as biliary and salivary,—consist of multiplied vesicles connected with a ramifying duct. Moreover, it is a well-ascertained fact that, even in the highest organisms, the functions of glandular structures (especially of those concerned in excretion) are to a certain degree vicarious with each other; so that, when the secretion from one of them is checked, the system makes an effort to throw off, by another channel, the injurious products that would otherwise accumulate in the blood. What is the nature of the change in any secreting surface, that causes it thus to take on a new function, is a question upon which we can at present only speculate; we have no more certain knowledge of it than we have of the cause which occasions their normal actions. That there is some kind of affinity or attraction between the several membranous surfaces, and the matters which they respectively eliminate, appears from the fact that of the foreign substances which are occasionally absorbed into the blood, some pass off invariably by one channel, and some by another; and that, in general, such substances have a particular action upon the glands by which they are eliminated, as is seen in the diuretic operation of neutral salts.

[There can scarcely be a more beautiful illustration of the doctrine, that physiology is as capable as any other science of being reduced to general principles, and that these principles must, if valid, be of *universal* application, than the fact that the process of secretion is performed, in animals as in plants, by the agency of *cells;* and that however complex the structure of the secreting organ, these simple bodies constitute its really operative part. The progress of comparative anatomy had shown that neither its form nor its internal arrangement could have any essential connection with the nature of its product; since even those glands (the liver and the kidney for example) in which there is the greatest peculiarity of structure, make their first appearance in the simplest possible form. Still something was wanting to prove that the structural elements immediately concerned are in all instances the same; and there seemed no analogy whatever between the secreting *membrane* of the animal and the secreting *cell* of the plant. The doctrine was first propounded by Purkinje, adopted and extended by Henle, and fully confirmed by the interesting researches of Goodsir and Bowman, that true *secretion*,—that is, the elaboration from the blood of certain of its solid contents, which previously existed there in a form more or less different from that in which they afterwards present themselves,—is always performed by the intervention of cells; which, as a part of their regular vital actions, withdraw these ingredients from the blood and afterwards set them free by their own rupture or dissolution. The process is thus strictly analogous to that of nutrition; since *every* cell, in the progress of its development, forms certain peculiar products out of the alimentary materials supplied to it; and just as the cells at the extremities of the villi select from

the chyme the nutritive portion which is to be introduced into the absorbent vessels, so do the cells that line the secreting tubuli select from the blood the effete particles it is *their* peculiar province to assimilate, and discharge them into the canals by which they will be carried out of the system. As Mr. Goodsir very justly remarks, "There are not, as has hitherto been supposed, two vital processes going on at the same time in the gland, growth and secretion; but only one, viz. growth. The only difference between this kind of growth and that which occurs in other organs is, that a portion of the product is, from the anatomical condition of the part, thrown out of the system." (Transactions of the Royal Society of Edinburgh, vol. xv., p. 302.)

There cannot be a better illustration of this view than the nature of *fat*, the production of which is exactly the intermediate link required to connect the two processes. The adipose tissue consists of cells, by the action of which the fatty matter is elaborated from the blood; instead, however, of being thrown out of the system, it remains stored up in their cavities until it is required for use within the body; and it must then be taken into the circulation by a process resembling the first absorption of aliment. Now a certain proportion of fatty matter is normally found in the secreting cells of the liver, and this quantity may be very much increased, as Mr. Bowman has shown, especially in diseases which obstruct the pulmonary circulation. The fat elaborated by *these* cells is destined to be thrown off from the system; and thus we perceive how much the anatomical position of the cells has to do with the result. Mr. Gulliver has communicated to the Author an interesting observation on the state of the secreting cells of the liver in jaundice, as witnessed by him in two cases. They were found to contain an unusual quantity of biliary matter, (easily distinguished by its colour,) which was collected chiefly around the nuclei, but was also scattered throughout the cell. Some of the cells were nearly opaque from the great quantity of biliary matter contained in them. In healthy cells of the liver the same appearance is not seen; for they are of a light brown colour and almost transparent. It would be interesting to examine the state of the hepatic cells, in those cases in which there is not a retention but a suppression of the secretion. Another interesting example of abnormal secretion has been mentioned to the Author by the same industrious observer. On examining the so-called *piogenic membrane* lining a chronic abscess, he found it to consist of pus-like globules, strongly resembling the colourless corpuscles of the blood, with minuter molecules, and united by fibrous fibrils; altogether very much like the false membrane which he has depicted as lining a tuberculous cavity (Philosophical Magazine, Nov. 1842). The contents of the abscess were common pus, mixed with a considerable quantity of fibrinous matter in masses of variable size,—the concrete or lardaceous pus of the French. The *secretion* of the purulent fluid, therefore, takes place in such instances from a membranous surface chiefly composed of cells analogous to those which are present in the *liquor puris* in greater or less amount.

The production of cells, as an integral part of the normal process of secretion, has been demonstrated by Mr. Goodsir in a considerable variety of instances; and he has further shown that what is ordinarily termed an *acinus* is nothing more than a parent-cell filled with progeny. This statement may also, as appears from late researches, be applied to the lungs, in which the air-tubes do not terminate, as maintained by Reissessen and his followers, in single dilated cæca, but open into a system of communicating beaded canals, forming a kind of acinus. These beaded canals are evi-

dently composed of cells partly fused together; and by the comparison of their state in animals of different ages, it seems that they are all developed from the cell in which the air-tube terminates, and that they continue to increase in number from the period of birth to adult age. The fact already stated, respecting the function of the red corpuscles of the blood and their connection with the respiratory function, supplies the required proof that respiration takes place through the medium of cells. But it may be questioned whether such agency is necessary where, as in insects, the air comes into more immediate contact with the blood; the change being of a chemico-physical character, and not truly vital.

The structure of the testes also, and the nature of their product, have an interesting connection with the structure and functions of the ordinary secreting organs. It was ascertained by Wagner that the most characteristic portion of the testes, throughout the animal kingdom, are the cells in which the spermatozoa are generated. These cells are found among the lower animals to lie in the midst of other tissues, and to set free their products by rupture, just as do their secreting cells. In the higher animals the process cannot be so well observed, since the cells lie in a testis of more complex construction, which seems destined to form some other secretion; but still it takes place in a manner essentially the same; and thus the proof is complete, that in the animal, as in the plant, the organic functions are all performed through the agency of cells.—C.]

The Liver.—Secretion of Bile.

650. The *Liver* is probably more universally found throughout the Animal scale, than any other gland. Its form varies so greatly, however, in different tribes, that, without a knowledge of its essential structure, we should be disposed to question whether any identity of character exists amongst the several organs which we include under this designation. In the higher Polypes, for example, we find it to consist of a number of distinct follicles, lodged within the walls of the stomach, and pouring their secretion into its cavity by as many separate orifices; and it is more by the peculiar character of their secretion, than by any other distinction, that these follicles are recognised as hepatic. In the lower Articulata a very similar conformation is met with; but in the higher classes of this series, such as Insects, the follicles are prolonged into tubes of considerable extent. It is very curious to observe, in animals of such complex structure, that a few long tubes, closed at one end, and opening at the other into the alimentary canal, are all which they have to represent a Liver; but the wonder is readily accounted for, by keeping in view the extremely active respiration of these beings, which renders unnecessary any other complex apparatus for elaborating carbon from the system. On the other hand, among the Mollusca, the Liver attains a much greater development. Instead of the follicles being prolonged into tubes, (which is the usual form of the glandular system in Insects) they are very much increased in number, and arranged on the sides of canals of efferent ducts, which either separately pour their fluid into the intestine, or partially unite with each other before doing so. The Liver thus acquires a lobulated character, each lobe consisting of a duct with its branching follicles; and the whole organ forms a considerable proportion of the mass of the viscera, and is evidently of great importance in the economy of the animal. It is interesting to compare this complex structure with the very simple condition presented by the Liver in Insects; and, when we keep

in view the relative amount of respiration in the two groups of animals, we are at once struck with the fact, that the development of the Liver bears an inverse proportion to the opportunity afforded by the Respiratory organs for the aeration of the blood; it being peculiarly extended, when these, either from their small size, or from their employment in an aquatic medium, cannot perform their function with great activity. This conclusion is confirmed in an interesting manner by the fact, that the Crustacea, which have the general organization of Insects, but which inhabit the water and breathe by gills instead of by a complex system of air-tubes, possess a liver corresponding in form and in degree of development with that of the Mollusca.

651. In the Vertebrate Sub-kingdom, we may trace the operation of the same principle; but the internal structure of the liver, in the adult condition at least, is less easily demonstrated than it is in the lower classes, owing to its increased complexity of structure, and the closer union between its different parts. In Fishes and Reptiles, the liver is of considerable size, and seems to perform a very important part in the decarbonization of the blood; its form is adapted to that of the cavity in which it is lodged, sometimes one lobe only being developed. In Birds, on the other hand, whose respiration is so much more active, it is much smaller, but is placed on the median line, in conformity with the general symmetry of their internal as well as external organs (§ 51). In Mammalia, also, it is comparatively small; but, though reduced in proportional size, it is at the same time much more compact and firm than in the lower Vertebrata. The liver of Man is much less developed than that of many other Mammalia, and presents, as rudimentary indications, certain organs which are elsewhere fully developed. The whole mass, which we are accustomed to describe as consisting of a right and left lobe, does in reality form but one (there being no real division between its two portions), which must be regarded as the central lobe; the lobulus Spigelii is the rudiment of a second or right lobe, and the lobulus caudatus is a lobule developed from it. In the Carnivora and Rodentia, which present the most complex form of liver that we meet with among Mammalia, there are five distinct parts;—a central or principal lobe, corresponding with the principal part of the liver of Man; a right lateral lobe, with a lobular appendage, corresponding to the lobulus Spigelii and the lobulus caudatus; and a similar lobe and lobule on the left side.

652. The gall-bladder is an appendage to the Liver of which we find no traces in the Invertebrata. It may be regarded as simply a dilatation of the efferent duct, more or less prolonged from it, adapted to store up the hepatic secretion against the time when it may be required. In Fishes it frequently, but by no means constantly, presents itself; in Reptiles, on the other hand, it invariably exists. In Birds it is occasionally absent, even in species closely allied to others that possess it, and without any marked difference in the food, habits, &c., of the two. In Mammalia, again, it is frequently absent, especially among herbivorous animals; sometimes, on the other hand, two are present, a second or accessory gall-bladder being formed upon the ductus communis choledochus, which elsewhere not unfrequently presents a dilatation in the same situation.* In the Human species the gall-bladder is rarely absent, except in cases of malformation depending upon general arrest of development, in which several organs are involved. The excretory ducts of the liver and gall-bladder have three coats,—an internal or mucous, a middle or fibrous, and an external or cellular. The internal coat is continu-

* In the first Giraffe dissected by Mr. Owen, no gall-bladder was found; in the second there were two.

ous with the mucous membrane of the intestinal tube into which it opens; and the whole glandular structure may indeed be considered as a complex prolongation of this, copiously supplied with blood-vessels, and packed into the smallest possible compass. The middle or fibrous coat bears a considerable resemblance in aspect to that of the arteries; in its properties, however, it is still more nearly allied to true muscle, being capable of exhibiting contraction on the application of stimuli to the ganglionic nerves supplying it (§ 200); and in some instances of obstruction it has presented an appearance very closely resembling that of the muscular coat of the alimentary canal.* Dr. Davy has pointed out, that the mucous coat of the ductus communis is disposed in valve-like folds, in such a manner as to prevent the reflux of the bile or of the contents of the intestine.

653. The liver may be regarded as essentially consisting of the ramifications of the hepatic duct, which are in close relation with those of the portal vein and hepatic artery, that serve to convey the blood to the minutest parts of this organ, and with those of the hepatic vein, which return it to the heart, after it has been subservient to the nutrition of the structure and to the elaboration of the secretion. Besides these, the liver contains lymphatics and nerves; the latter are chiefly derived from the sympathetic system, and are distributed on the walls of the vessels and ducts. These various portions of the structure are connected together by a fibrous tissue, to which the name of Glisson's capsule has been given. For our present knowledge of their ultimate arrangement, we are almost entirely indebted to Mr. Kiernan,† whose account of them will be here followed. When the Liver is closely examined with the naked eye, it is seen to be made up of a great number of small granular bodies, about the size of a millet seed, of an irregular form, and presenting a number of rounded projecting processes upon their surface. These are commonly termed *lobules*, although by some Anatomists they are spoken of as *acini*. When divided longitudinally, they have a somewhat foliated appearance, arising from the distribution of the hepatic vein, which, passing into the centre of each division, is termed the *intra*-lobular vein. The exterior of each lobule is covered by a process of the capsule of Glisson; and its substance is composed of the minute ramifications of the before-mentioned vessels, arranged in the manner presently to be described, the spaces between which are filled up with a parenchyma, composed of nucleated cells, as shown in the accompanying figure. The structure of each lobule, then, gives us the essential characters of that of the whole gland.‡

654. The lobules, when transversely divided, are usually found to present somewhat of a pentagonal or a hexagonal shape, the angles being

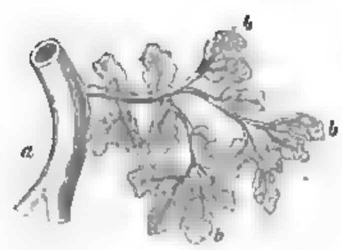
* In the Horse and Dog this coat is clearly muscular.

† Philosophical Transactions, 1833.

‡ The nucleated cells of the Liver have recently been made the subject of observation by Mr. Bowman (Medical Gazette, Jan. 1842); and he has arrived at some interesting results in regard to them. These cells seem to be of the same nature with the epithelium-cells of other glands (§ 668, Fig. 70); but as to their exact position in regard to the terminations of the biliary plexus, no certain information has yet been obtained. In their ordinary state, they contain "one, or two, or more globules of fatty matter, irregularly placed, and of variable bulk." But in the condition of the Liver known as "fatty degeneration," which presents itself in about one-third of the total number of cases of phthisis, "the nucleated cells are gorged with large masses of the fatty deposit, which augment their bulk, and more or less obscure their nuclei." It is interesting to remark that, in these cases, an increased secretion is taking place in the liver, in consequence of the imperfect play of the lungs; and that the deposition of fatty matter in the nucleated cells is not a new action, but only a natural action augmented in degree. Both these facts have a general application of some importance, as explained in the following paragraph.

generally somewhat rounded, so as to form a series of passages, or *inter-lobular spaces*; in these lie the branches of the vena porta and of the hepatic artery and duct, from which are derived the plexuses that compose the lobules. Each lobule, when examined with the microscope, is found to be apparently

Fig. 59.



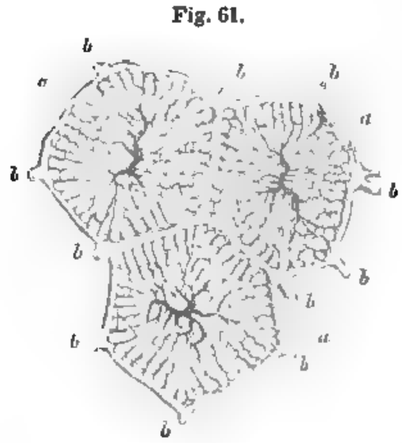
Connection of the lobules of the liver with the hepatic vein; *a*, trunk of the vein, *b*, *b*, lobules depending from its branches, like leaves on a tree; the centre of each being occupied by a venous twig,—the intralobular vein. (After Kiernan.)

Fig. 60.

A. Lobules of human liver, with ramifications of the hepatic vein. B. Nucleated cells, composing the parenchyma of the gland. (After Wagner.)

composed of numerous minute bodies of a yellowish colour, and of various forms, connected together by vessels; to these the name of *acini* was given by Malpighi, and to these, if they deserve a name, it ought to be restricted. They will be presently shown, however, to be nothing else than the irregular islets left between the meshes of the plexus formed by the ultimate ramifications of the portal vein. The Vena Porta, it will be recollected, is formed by the convergence of the veins which return the blood from the chylopoietic viscera; and there is reason to believe that it also receives the blood which is conveyed to the liver for the purpose of nutrition by the hepatic artery. As it is an afferent, not an efferent vessel, it has a strong claim to the character of an artery, even although it conveys venous blood. Like an artery, it gradually subdivides into smaller and yet smaller branches: and at last forms a plexus of vessels, which lies in the interlobular spaces, and spreads, with the freest inosculation, throughout the entire liver. To these vessels, the name of *interlobular veins* is given by Mr. Kiernan. They ramify in the capsules of the lobules, covering with their ramifications the whole external surface of these; and then enter their substance. When they enter the lobules, they are termed *lobular* veins; and the plexus formed by their convergence from the circumference of each lobule towards its centre (where their ultimate ramifications terminate in those of the intra-lobular or hepatic

Fig. 61.

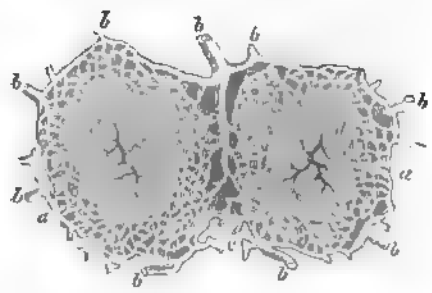


Horizontal section of three superficial lobules, showing the two principal systems of blood-vessels; *a*, *a*, intralobular veins, proceeding from the hepatic veins; *b*, *b*, interlobular plexus, formed by branches of the portal veins. (After Kiernan.)

vein) is designated as the *lobular venous plexus*. In the islets of this plexus (the acini of Malpighi) the ramifications of the hepatic duct are distributed, in the manner next to be described.

655. The hepatic duct forms, by its subdivision and ramification, an interlobular plexus of a very similar character; but the anastomosis between the branches going to the different lobules is less intimate than that of the interlobular veins, and cannot be directly demonstrated, although Mr. Kiernan thinks that his experiments leave but little doubt of its existence,—a communication (which cannot be seen to be established by any nearer channel) being proved to exist between the right and left primary subdivisions of the duct. The interlobular ducts ramify upon the capsular surface of the lobules, with the branches of the portal vein and hepatic artery; they then enter its substance, and subdivide into minute branches, which anastomose with each other, and form a reticulated plexus, termed by Mr. K. the *lobular biliary plexus*. This plexus constitutes the principal part of the substance of the lobule, and, when seen through the meshes of the portal plexus, gives rise to the appearance of cœcal terminations of ducts. The ultimate terminations of these ducts have not, however, been traced in the adult liver of any of the higher animals, although they are sufficiently evident in the embryonic condition. From the analogy of other organs, there would seem good reason to believe, that the ultimate ramifications of the hepatic ducts anastomose freely together, and that they form a network, in which their terminations are lost, as it were, without forming true cœca.* This view of the matter finds confirmation in the curious fact pointed out by Mr. Kiernan, that, in the left lateral ligament the essential parts of a lobe are found in their simplest form and arrangement. From the edge of the liver next to the ligament, numerous ducts emerge, which ramify between the two layers of the peritoneum of which the ligament is composed. They are accompanied by branches of the portal and hepatic veins, and of the hepatic artery, which also ramify in this ligament, especially around the parietes of the ducts. These ducts, of which some are occasionally of considerable size, divide, subdivide, and anastomose with each other; and the meshes formed by the network of larger or excreting ducts, are occupied by minute plexuses of their ultimate ramifications or secreting ducts.

Fig. 62.



Horizontal section of two superficial lobules, showing the interlobular plexus of biliary ducts; *a*, *a*, intralobular veins; *b*, *b*, trunks of biliary ducts, proceeding from the plexus which traverses the lobules; *c*, interlobular tissue; *d*, parenchyma of the lobules. (After Kiernan.)

656. The Hepatic Artery sends branches to every part of the Liver, supplying the walls of the portal and hepatic veins, and of the hepatic ducts, as well as Glisson's capsule. The principal distribution of its branches, however, is to the lobules, which they reach, in the same manner with the portal vessels and biliary ducts, by spreading themselves through the interlobular spaces. There they ramify upon the interlobular ducts,

* See Wilson in Cyclopædia of Anatomy and Physiology, Vol. III. p. 170.

and upon the capsular surface of the lobules, which they then penetrate; their minuteness prevents their distribution within the lobules from being clearly demonstrable; but, as they enter along with the biliary ducts, there can be little doubt that, here as elsewhere, they are principally distributed upon the walls of these. As to the ultimate termination of the capillaries of the hepatic artery,—whether they enter the portal plexus or the hepatic vein, —there is a difference of opinion amongst anatomists; the former view being upheld by Kiernan, the latter by Müller. The question is a very interesting one in a physiological point of view; since, if the former account be the true one, the blood which is brought to the liver by the hepatic artery becomes subservient to the secretion of bile, only by passing into the portal plexus; whilst, if the latter be the correct statement, either the arterial blood is not at all subservient to the formation of bile, or the secretion can be elaborated from the arterial capillaries. The experiments of Mr. Kiernan have satisfactorily proved, that the intra-lobular or hepatic veins cannot be filled by injection from the hepatic artery, though they may be readily filled from the portal plexus; whilst, on the other hand, there is reason to believe that a very fine injection into the hepatic arteries, will find its way into the portal plexus.* It is certain that all the branches of the hepatic artery, of which the termination *can* be ascertained, end in the vena porta; a free capillary communication existing between their two systems of branches, on the walls of the larger blood-vessels and ducts. According to Müller, there is an ultimate plexus of capillary vessels, with which all the three systems freely communicate; but for this idea there is no adequate foundation; and it is inconsistent with the fact just stated, that injection into the hepatic artery does not return by the hepatic vein.

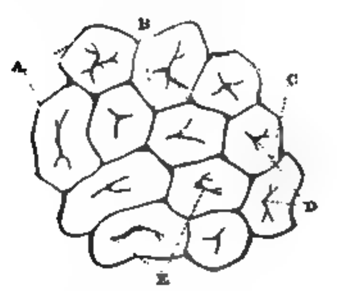
657. It now only remains to describe the Hepatic Veins, the branches of which occupy the interior of the lobules, and are termed *intra*-lobular veins (*a*, *a*, Figs. 61 and 62). On making a transverse section of a lobule, it is seen that the central vessel is formed by the convergence of from four to six or eight minute venules, which arise from the processes upon the surface of the lobule. In the superficial lobules (by which term are designated those lobules which lie upon the exterior of the glandular substance, not only upon the surface of the liver, but also against the walls of the larger vessels, ducts, &c.,) the intralobular veins commence directly from their surface; and the minute venules of which each is composed may be seen, in an ordinary injection, converging from the circumference towards the centre, as in the transverse section of other lobules. The intralobular veins terminate in the larger trunks, which pass along the bases of the lobules, collecting from them their venous blood; these are called by Mr. Kiernan *sublobular* veins. The main trunk of the hepatic vein terminates in the ascending vena cava.

658. The knowledge of the distribution of the biliary ducts, and of the two chief systems of blood-vessels, in the lobules of the liver, has enabled Mr. Kiernan to give a most satisfactory explanation of appearances, by which pathological anatomists had been previously much perplexed. When the Liver is in a state of anæmia (which rarely happens as a natural condition, although it may be induced by bleeding an animal to death) the whole substance of the lobules is pale, as represented in Fig. 63. In general, however, the Liver is more or less congested at the moment of death; and this congestion may manifest itself in several ways. The whole sub-

* This is stated to have been the case in the injections of Lieberkühn; although Mr. Kiernan has not succeeded in effecting it.

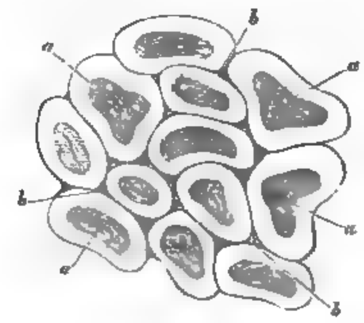
stance may be congested; in which case the lobules present a nearly uniform dark colour throughout their substance,—their centres being usually more deeply-coloured than the margins. An appearance more frequently offered after death, however, is that represented at Fig. 64, and termed by Mr. Kiernan the *first* stage of *hepatic venous* congestion. In this, the isolated

Fig. 63.



A. Angular lobules in a state of anæmia, as they appear on the external surface of the liver; B, interlobular spaces; C, interlobular fissures; D, intralobular veins, occupying the centres of the lobules; E, smaller veins, terminating in the central veins.

Fig. 64.



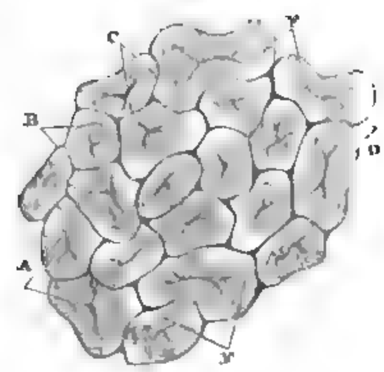
a. Rounded lobules in first stage of hepatic venous congestion; as they appear on the surface of the liver; *b*, interlobular spaces and fissures.

centres of the lobules alone present the colour of sanguineous congestion; and the surrounding substance varies from a yellowish white, yellow, or greenish colour, according to the quantity and quality of the bile which it contains. The accumulation of the blood in the hepatic veins, and the emptiness of the portal plexus, is evidently due to the continuance of capillary action after the general circulation has ceased;—a circumstance to which we find an exact parallel, in the emptiness of the systemic arteries, and the fulness of the veins, after most kinds of death. In the *second* stage of hepatic venous congestion, the accumulation of blood is found not only in the intralobular veins, but even in parts of the portal or lobular venous plexus. The parts which are freest from it are those surrounding the interlobular spaces; so that the non-congested substance here appears in the form of circular or irregular patches, in the midst of which the spaces and fissures are seen (Fig. 65).* Although the portal as well as the hepatic venous system is thus involved in this form of congestion, yet, as the obstruction evidently originates in the latter, the term given by Mr. Kiernan is still applicable; and it is important to distinguish this appearance from that next to be described. The second stage of hepatic venous congestion very commonly attends disease of the heart, and other disorders in which there is an impediment to the venous circulation; in combination with accumulation in the biliary ducts, it gives rise to those various appearances which are known under the name of dram drinkers' or nutmeg liver. The other form of partial congestion arises from an accumulation of blood in the portal veins, with a reverse condition

* This very common aspect of the liver, which presents numerous modifications, has been a source of great perplexity to those who have studied the minute anatomy of this organ, and has even led Anatomists of the highest eminence into serious errors. See Cyclop. of Anat. and Physio. Vol. III. pp. 185, 186.

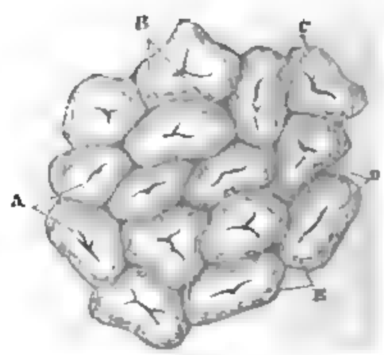
of the hepatic or intralobular veins; in this condition, which Mr. K. designates as *portal venous congestion*, the marginal portions of the lobules are of deeper colour than usual, and form a continuous network, the isolated

Fig. 65.



A, lobules in the second stage of hepatic venous congestion; B and C, interlobular spaces; D, congested intralobular veins; E, congested patches, extending to the circumference of the lobules, F, non-congested portions of lobules.

Fig. 66.



A, lobules as they appear on the surface in a state of portal venous congestion; B, interlobular spaces and fissures; C, intralobular hepatic veins, containing no blood; D, the central portions in a state of anæmia; E, the marginal portions in a congested state.

spaces between which are occupied by the non-congested portions (Fig. 66). This is a very rare occurrence; having been seen by Mr. K. in children only. These differences fully explain the diversity of the statements of different anatomists as to the relative position of the so-called *red* and *yellow* substances; for it now appears that the *red* substance is the *congested* portion of the lobules, which may be either interior or exterior, or irregularly disposed; whilst the yellow is the non-congested part, in which the biliary plexus shows itself more or less distinctly.

659. Another very interesting form of pathological change in the aspect of the Liver, which the knowledge of the structure of the lobules enables us to comprehend, is that to which the name of *Cirrhosis* has been given. This has been erroneously attributed to the presence of a new deposit, analogous to that of tubercular matter; but it is really due to atrophy and partial congestion in the liver itself. It is described by Laennec as usually presenting itself in small masses, varying in size from a cherry-stone to a millet-seed, and scattered through the substance of the liver. When these are minute, and closely set, they impart what appears at first to be a uniform brownish-yellow tint to the divided surface of the liver; but when the tissue is more attentively examined, their separation becomes evident. These small masses are not distinct lobules in a variable state of hypertrophy (as supposed by Cruveilhier), but small uncongested patches, composed of parts of several adjoining lobules, and having one or more interlobular spaces for a centre; and the biliary plexuses of these, being filled with bile, gives them their yellow colour. On the other hand, there is an atrophy, more or less complete, of the portions of the substance of the liver intervening between them; so that the bulk of the whole organ is much diminished, very commonly to one half, and sometimes to one third, of its original size.

660. In regard to the embryonic development of the Human Liver, a considerable part of our information must necessarily be derived from the study of that of other animals; and this is not so much from Mammalia as from Birds; since the development of this organ commences so early in the former, its phases are so rapidly hurried through, and its evolution so soon completed, that the process cannot be continuously watched. In the chick, the rudiments of the liver are found at the commencement of the third day of incubation, in the form of two cœcal pouches, which are prolonged from the intestinal tube; these carry before them a fold of the vascular layer, from which the blood-vessels subsequently originate; and they soon begin to ramify in this, sending off branches, of which the cœcal extremities are still evident. At the end of the fourth day, the tubuli and their ramifications have attained a considerable size; and they approach each other and coalesce at the base, entering the intestine by an orifice common to the two. In this process, it is easy to recognise the analogy to the succession of forms which we encounter in ascending the animal scale. The size and density of the organ are gradually increased; but it is not until several days afterwards, that the gall-bladder is developed. In the Human embryo, the formation of the liver begins at about the third week of intra-uterine existence; the organ is from the first of very large size, when compared with that of the body; and between the third and the fifth week, it is one half the weight of the entire embryo. It is at that period divided into several lobes. By the third lunar month, the liver extends nearly to the pelvis, and almost fills the abdomen; the right side now begins to gain upon the left; the gall-bladder begins to appear at this time. The subsequent changes chiefly consist in the consolidation of the viscus, and the diminution of its proportioned size. Up to the period of birth, however, the bulk of the liver, relatively to that of the entire body, is much greater than in the adult; the proportion being as 1 to 18 or 20 in the new-born child, whilst it is about 1 to 36 in the adult: and the difference between the right and left sides is still inconsiderable. During the first year of extra-uterine life, however, a great change takes place; the right lobe increases a little or remains stationary, whilst the left lobe undergoes an absolute diminution, being reduced nearly one-half; and as, during the same period, the bulk of the rest of the body has been rapidly increasing, the proportion is much more reduced during that period, than in any subsequent one of the same length. According to Meckel, the liver of the newly-born infant weighs one-fourth heavier than that of a child of eight or ten months old; and as the weight of the whole body is more than doubled, during the same time, it is obvious that the change in the proportion of the two must be principally effected at this epoch.

661. Previously to birth, the Liver is the only decarbonizing organ, the lungs being at that time inert; but as soon as the latter come into play, they separate from the venous blood a large proportion of the carbon with which it is charged, and less blood is transmitted to the liver for this purpose. The diminution in the quantity of the blood circulating through this organ, is extremely rapid, and is usually very evident within a short time after birth, in the comparative paleness of its substance. It has been proposed to give this fact a practical bearing, in those judicial inquiries which are directed to the determination of the question whether or not an infant has respired after birth; it having been conceived that the diversion of the current of the blood from the liver to the lungs, consequent upon the first inspiration, would be sufficient to make a certain difference in their relative weights, if that inspiration had taken place. More careful

and extended observations, however, have satisfactorily proved [illegible] though an increase in the weight of the lungs, and a diminution o[illegible] the liver, are generally found to exist after respiration has been [illegible]blished, they are not by any means constantly produced when the [illegible]tions have been feeble, as they frequently are for some hours or d[illegible] birth; whilst, on the other hand, it is not uncommon to meet [illegible] that have not breathed, with lungs as heavy, and livers as light, [illegible] average of those which have respired.*

662. We have now to consider the conditions under which the se[illegible] Bile takes place; and one of the most important of these, is the [illegible] of the blood with which the organ is supplied. We have seen tha[illegible] anatomical reason for the belief, that the blood supplied by the [illegible] artery is not directly concerned in the secretion; but that it fir[illegible] for the nutrition of the organ, and then, passing into the portal sy[illegible] the same manner as does the blood of the mesenteric and other [illegible] forms part of the mass of venous blood from which the bilia[illegible] elaborate their fluid. This view is borne out by the results of experi[illegible] of pathological observation. Thus, if the vena porta be tied, the se[illegible] bile still continues, though in diminished quantity; and several c[illegible] on record, in which, through a malformation, the vena porta term[illegible] the vena cava without ramifying through the liver, and in which s[illegible] of bile took place, evidently from the blood of the hepatic artery w[illegible] become venous by circulating through the substance of the liver: [illegible] blood appears* to have passed into the ramifications of the umbi[illegible] which formed a plexus in the lobules, exactly resembling the [illegible] portal plexus. It must be remembered, however, that in all these [illegible] the arterial blood will become abnormally charged with the ele[illegible] [illegible]

and the congestion of the portal system; this last results from the same cause as that which stagnates the blood in the lungs when there is deficient respiration (§ 548), and frequently occasions ascites and other disorders of the contents of the abdomen. An abnormal accumulation of the elements of the bile in the blood is habitual in some persons; and it produces a degree of indisposition to bodily or mental exertion, which it is difficult to counteract. It may often be recognised by the accumulation of dark mucus having distinctly the taste of bile, on the surface of the tongue, especially during the night; this secretion being apparently eliminated by the mucous membrane of the tongue, when the function of the liver is not duly performed.

663. Much discussion has taken place among Chemists, in regard to the proximate principles of the Biliary secretion, a great number of analyses having been made, amongst the results of which there is a great want of conformity. The discrepancies principally arise from this source,—that the secretion is acted on with great facility by chemical reagents, so that many of the component parts which have been enumerated are not true *educts*, but are *products* of the operations to which the fluid has been subjected. The proportion of solid matter is usually from 9 to 12 per cent.; and nearly the whole of this consists of a substance peculiar to bile, in which the oleaginous character certainly predominates. This substance contains a large proportion of carbon and hydrogen, with little or no azote. We are probably to distinguish in it two very different compounds. The first of these is termed *Cholesterine;* it is a white crystallizable fatty matter, somewhat resembling spermaceti, free from taste and odour, not soluble in water, but dissolving freely in alcohol, from which it is deposited on cooling in pearly scales. It is almost entirely composed of carbon and hydrogen; its constitution being 37 Carbon, 32 Hydrogen, 1 Oxygen. This may be pretty certainly considered as a real proximate element of the bile, since it frequently separates itself, when present in superabundant quantity, forming biliary concretions, which are sometimes composed of this alone, but more commonly contain a small portion of resinous and colouring matter. Moreover, it may be obtained by a chemical process of no great complexity from the serum of the blood; and it is not unfrequently deposited as a result of diseased action in other parts of the body; especially in the fluids of local dropsies, as hydrocele, ovarian dropsy, &c. The other substance, now termed *Bilin* (formerly Picromel), is that to which the peculiar taste of the bile, which is at the same time bitter and sweet, is due. According to the account most recently given of this compound, by Berzelius, it is a translucent, colourless, inodorous mass, without crystallization; it is very soluble in water and alcohol, but insoluble in ether. It contains nitrogen, and is decomposed by heat, with the formation of ammoniacal products. Bilin is a readily alterable substance; it is decomposed by acids into five different substances, namely, ammonia, taurin, fellinic and cholinic acids, and dyslysin; and it appears that this decomposition may take place in the bile of the living body. The last of these products appears to be that which has been spoken of by some Chemists as the resin of the bile. The colouring matter of the bile is now termed Biliverdin. It contains no azote; and that of the ox appears to be identical with the chlorophyll of plants. When exposed to the air, it becomes of a deep green, absorbing oxygen; and the same change is produced by nitric acid, the liquor soon passing, however, to a red hue. It frequently takes place within the body, in cases of jaundice; but more especially in the urine. Though the colouring matter is usually present but in small quan-

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manner. It would not seem improbable, that the liver acts towards the absorbed matters which enter the blood by the mesenteric veins, the same part which the lungs perform for those which are introduced through the lymphatic system; namely the affording an opportunity for the excretion of superfluous or injurious substances contained in the absorbed fluid before it enters the general current of the circulation. There is every reason to believe that the conversion of chyle into blood is a slow process, requiring the prolonged influence of the latter fluid upon the former; during this influence many chemical changes take place, which are almost certain to be attended with an extrication of carbon and hydrogen, these being the ingredients of which the chyle contains most when compared with blood; and for the extrication of these, the lungs and liver afford ready means. Hence we see why the lacteal system should terminate in a venous trunk near the heart, so that the fluid discharged by it will proceed at once to the lungs; and why the liver, wherever it has a distinct circulation, should receive the blood from the walls of the intestines.* This view derives interesting confirmation from the experiments of Cruveilhier, on the artificial production of purulent deposits by injection of mercury into the veins. He found that, when the mercury was introduced into any part of the general venous system, abscesses in the lungs were induced, each inclosing a globule, the irritation occasioned by which was the cause of the purulent deposit. When the mercury was introduced into one of the intestinal veins, on the other hand, similar purulent deposits occurred in the liver. It is well-known that abscesses in the lungs and liver are very common sequelæ of wounds of the head, and of surgical operations, especially those involving bones; and there seems good reason to believe, that in such cases pus is actually carried along with the current of blood into the lungs and liver; and that, like the globules of mercury, not being susceptible of elimination by these two great emunctories, it acts as a disturbing cause, and occasions disease in their tissue. The fact that a considerable amount of copper may be detected in the substance of the liver, after the prolonged introduction of its salts into the system, seems to add weight to this view of its function. It is yet to be ascertained, however, why some substances should be arrested in this organ, whilst others are allowed to pass.

The Kidneys.—Secretion of Urine.

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and extended observations, however, have satisfactorily proved that, although an increase in the weight of the lungs, and a diminution of that of the liver, are generally found to exist after respiration has been fully established, they are not by any means constantly produced when the inspirations have been feeble, as they frequently are for some hours or days after birth; whilst, on the other hand, it is not uncommon to meet, in infants that have not breathed, with lungs as heavy, and livers as light, as in the average of those which have respired.*

662. We have now to consider the conditions under which the secretion of Bile takes place; and one of the most important of these, is the character of the blood with which the organ is supplied. We have seen that there is anatomical reason for the belief, that the blood supplied by the hepatic artery is not directly concerned in the secretion; but that it first serves for the nutrition of the organ, and then, passing into the portal system (in the same manner as does the blood of the mesenteric and other arteries), forms part of the mass of venous blood from which the biliary tubes elaborate their fluid. This view is borne out by the results of experiment and of pathological observation. Thus, if the vena porta be tied, the secretion of bile still continues, though in diminished quantity; and several cases are on record, in which, through a malformation, the vena porta terminated in the vena cava without ramifying through the liver, and in which secretion of bile took place, evidently from the blood of the hepatic artery which had become venous by circulating through the substance of the liver; and this blood appears† to have passed into the ramifications of the umbilical vein, which formed a plexus in the lobules, exactly resembling the ordinary portal plexus. It must be remembered, however, that in all these instances the arterial blood will become abnormally charged with the elements of bile; since the blood of the chylopoietic viscera, from which it ought to have been separated, returns to the heart without undergoing any such purification: and the secretion of bile from the blood supplied by the hepatic artery under such circumstances cannot, therefore, be considered as proving that the arterial blood is ordinarily concerned in the secretion to the same degree. That the proximate elements of the bile accumulate in the blood, when from any cause the secretion is suspended, is a fact now well ascertained; and this satisfactorily accounts for the disturbance of the other functions, especially those of the nervous system, which then ensues. When the suppression is complete, the patient suddenly becomes jaundiced, the powers of that system are speedily lowered (almost as by a narcoctic poison), and death rapidly supervenes.‡ When the secretion is diminished, but not suspended, the same symptoms present themselves in a less aggravated form. It is probable that much of the disorder in the functions of the brain, which so constantly accompanies deranged action of the digestive system, is due to the less severe operation of the same cause, —the partial retention within the blood of certain constituents of the bile, which should have been eliminated from the circulating fluid. In such a condition we derive great benefit from the use of mercurial medicines; which by stimulating the liver to increased action, cause the removal of the morbific agent from the blood. Deficient secretion of the liver may be recognised as the cause of this and of other diseases, by the paleness of the alvine evacuations, the diffused yellowness of the surface of the body,

* See Dr. Guy, in Edinb. Med. and Surg. Journ. Vols. LVI. and LVII.

† This, at least, was found to be the case in the only instance in which the liver was examined with sufficient care.

‡ See Dr. Alison in Edinburgh Medical and Surgical Journal, Vol. XLIV. p. 287.

and the congestion of the portal system; this last results from the same cause as that which stagnates the blood in the lungs when there is deficient respiration (§ 548), and frequently occasions ascites and other disorders of the contents of the abdomen. An abnormal accumulation of the elements of the bile in the blood is habitual in some persons; and it produces a degree of indisposition to bodily or mental exertion, which it is difficult to counteract. It may often be recognised by the accumulation of dark mucus having distinctly the taste of bile, on the surface of the tongue, especially during the night; this secretion being apparently eliminated by the mucous membrane of the tongue, when the function of the liver is not duly performed.

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tity during health, it sometimes accumulates in disease, so as to produce solid masses, which include little else.*

{A different and very simple view of the constitution of bile has been given by M. Demarçay, which sustains the idea of Cachet, that bile is a species of soap. According to this chemist, bile is a compound of soda and an oily acid, to which he has given the name of *choleic*. It is not, however, a *choleate of soda*, which is decomposed by the weakest acids, whilst bile is not. Both Liebig and Dr. Prout (on Stomach and Renal Diseases, p. 510, 4th ed., 1843) agree in thinking the views of Demarçay as in general correct, although they admit that at present, they are imperfect.—M. C.}

664. The amount of the secretion of Bile appears to bear some proportion to that of the food digested. That its formation is continually going on to a certain degree, appears unquestionable; but that its quantity is greatly increased during the solution of food in the stomach, appears also to be well established. Whether the stimulus to the increased secretion at that period is occasioned by an increased flow of blood, or is propagated through the nervous system, there is no evidence; the analogy of the salivary, lachrymal, and other secretions would indicate the latter. In those animals which are most constantly ingesting food, we find no gall-bladder; for in them, the bile may be poured into the intestine as fast as it is formed. In those which only take food occasionally, on the other hand, and which are provided with a gall-bladder, the bile, when not required in the intestine, flows back into that reservoir. This reflux would appear due to the valve-like termination of the ductus communis in the walls of the intestine, which offers a certain resistance to the entrance of the fluid, unless it be propelled by some decided force. The flow of bile into the intestinal tube, when its action is needed there, is commonly imputed to the pressure of the distended duodenum against the gall-bladder; it may be doubted, however, whether the contractile power of the duct itself, does not afford important aid in the process; and it is easy to understand, from the known influence of the Sympathetic system of nerves upon it (§ 652), that peristaltic movements may be excited at the time when they are needed. It is an interesting fact, proving how completely the passage of bile into the intestine is dependent upon the presence of aliment in the latter, that the gall-bladder is almost invariably found turgid in persons who have died of starvation; the secretion formed at the ordinary slow rate having gradually accumulated, for want of demand. This fact is important in juridical inquiries.

665. Of the operation of the bile in the digestive process, enough has already been said (§ 442). No certain information has yet been obtained, whether any of the elements of the bile itself are absorbed in the form of chyle; or whether the bile acts simply as a precipitant, and is altogether cast out of the system, with the useless portion of the chyme. There can be no question, however, that by far the largest part of the secretion is destined to be entirely thrown off; and it would seem, from the character of its proximate elements, as if it were destined to remove from the blood its superfluous hydrocarbon,—whether this has been absorbed as such from the aliment, or has been taken up by the blood as effete matter, during the course of the circulation. The presence of azote in picromel, however, shows that some of the effete azotized compounds also are got rid of in this

* A full account of the latest researches of Berzelius on this subject will be found in Graham's Chemistry, pp. 1045—9.

manner. It would not seem improbable, that the liver acts towards the absorbed matters which enter the blood by the mesenteric veins, the same part which the lungs perform for those which are introduced through the lymphatic system; namely the affording an opportunity for the excretion of superfluous or injurious substances contained in the absorbed fluid before it enters the general current of the circulation. There is every reason to believe that the conversion of chyle into blood is a slow process, requiring the prolonged influence of the latter fluid upon the former; during this influence many chemical changes take place, which are almost certain to be attended with an extrication of carbon and hydrogen, these being the ingredients of which the chyle contains most when compared with blood; and for the extrication of these, the lungs and liver afford ready means. Hence we see why the lacteal system should terminate in a venous trunk near the heart, so that the fluid discharged by it will proceed at once to the lungs; and why the liver, wherever it has a distinct circulation, should receive the blood from the walls of the intestines.* This view derives interesting confirmation from the experiments of Cruveilhier, on the artificial production of purulent deposits by injection of mercury into the veins. He found that, when the mercury was introduced into any part of the general venous system, abscesses in the lungs were induced, each inclosing a globule, the irritation occasioned by which was the cause of the purulent deposit. When the mercury was introduced into one of the intestinal veins, on the other hand, similar purulent deposits occurred in the liver. It is well-known that abscesses in the lungs and liver are very common sequelæ of wounds of the head, and of surgical operations, especially those involving bones; and there seems good reason to believe, that in such cases pus is actually carried along with the current of blood into the lungs and liver; and that, like the globules of mercury, not being susceptible of elimination by these two great emunctories, it acts as a disturbing cause, and occasions disease in their tissue. The fact that a considerable amount of copper may be detected in the substance of the liver, after the prolonged introduction of its salts into the system, seems to add weight to this view of its function. It is yet to be ascertained, however, why some substances should be arrested in this organ, whilst others are allowed to pass.

The Kidneys.—Secretion of Urine.

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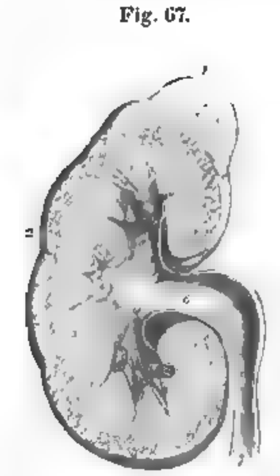
more evident form. They are uniformly composed of a congeries of prolonged tubes, sub-dividing and ramifying more or less, which spring from the ureter or efferent duct, and terminate either in blind extremities, or in a plexus formed by their inosculation. There are considerable va-

Fig. 67.



A section of the kidney, surmounted by the supra-renal capsule. 1. The supra-renal capsule. 2. The vascular portion. 3, 3. Its tubular portion, consisting of cones. 4, 4. Two of the calices, receiving the apex of their corresponding cones. 5, 5, 5. The three infundibula. 6. The pelvis. 7. The ureter.

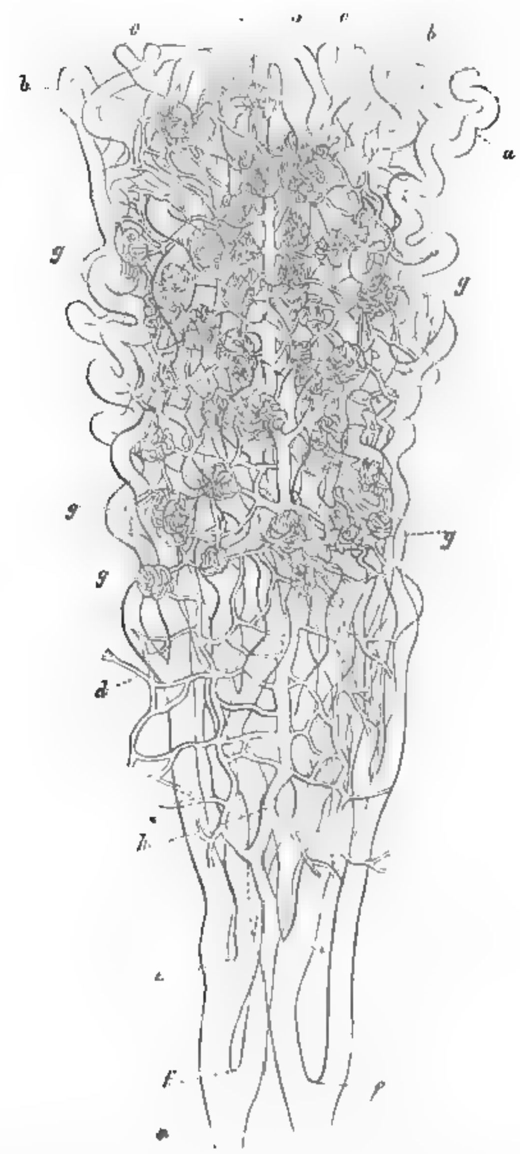
Fig. 68.

Portion of the kidney of a new-born infant. A. Natural size; *a*, *a*, Corpora Malpighiana, as dispersed points in the cortical substance; *b*, papilla. B A smaller part magnified; *a*, *a*, Corpora Malpighiana: *b*, tubuli uriniferi. (After Wagner.)

riations in the arrangement of these tubes, however, in different tribes of animals. In Fishes, the Kidneys very commonly extend the whole length of the abdomen; and they consist of tufts of uniform-sized tubules, which shoot out transversely at intervals from the long ureter. These tubes frequently divide into pairs, but without any great alteration in their diameter. They appear to terminate in cœcal extremities, without any inosculation; the number of bifurcations, and the degree of convolution, vary greatly in different species. The uriniferous tubes are connected together by a very loose cellular web. The structure of the gland in Reptiles appears to be essentially the same; its form, however, varies considerably in the different tribes, being greatly prolonged in the Serpents, and abbreviated in Tortoises. In the Crocodile, the distinction between the cortical and medullary portion begins to show itself; the tubes being nearly straight where they issue from the ureter, and being convoluted near the surface only of the lobes. The Corpora Malpighiana (§ 667), however, where they exist in this class, are scattered through the whole substance; not being confined, as in higher animals, to the cortical portion. In Birds, the urinary tubes, forming the several clusters, are more closely united together; they frequently ramify to a considerable degree. In the Mammalia, as in Man, there is an evident distinction between the straight and the convoluted portions of the system of tubes; the former character is seen in the *medullary* substance; the latter in the *cortical*. In nearly all below the Mammalia, the kidneys present externally a lobulated aspect, resulting from the want of union between the different bundles of tubes, which arise from separate parts of the ureter. In the kidney of the Mammalia, however, the ureter dilates into a capacious recep-

tacle, towards which the several bundles of uriniferous tubes converge, so that they open into it in close proximity with each other; and the lobules formed by these bundles are so closely brought together, that no appearance of a division presents itself, until a section of the gland is made. Among

Fig. 69.

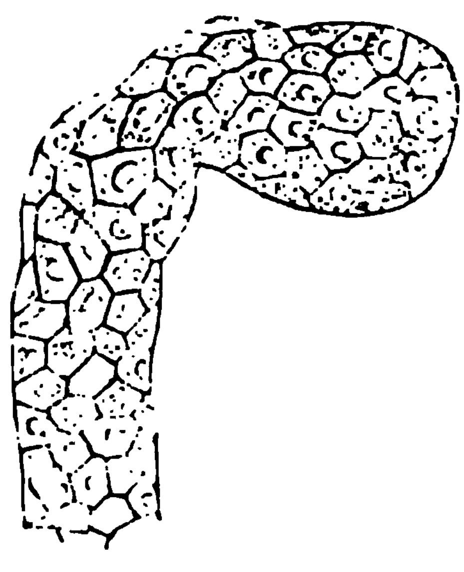


A small portion of the kidney, magnified about sixty times; *a*, cœcal extremity of a tubulus urini-ferus; *b*, recurrent loops of tubuli; *c*, *c*, bifurcations of tubuli; *d*, *e*, *f*, tubuli converging towards the papilla; *g*, *g*, *g*, Corpora Malpighiana, seen to consist of plexuses of blood-vessels, connected with a capillary network; *h*, arterial trunk. (After Wagner.)

some Mammalia, however, the lower form is still retained; and it is presented in the Human species also, at an early period of its fœtal development.

667. The distinction between the *cortical* and *medullary* parts of the Kidney essentially consists in this,—that the former is by far the most vascular, and the plexus formed by the tubuli uriniferi seems to come into the closest relation with that of the sanguiferous capillaries, so that it is probably the seat of the greater part of the process of secretion; whilst the latter is principally composed of tubes passing in a straight line from the former towards their point of entrance into the ureter. In this respect there is a considerable analogy of structure and comparative function, between the two parts of the kidney and the two parts of the brain. The adjoined figure (68) represents the appearances presented by a portion of an injected kidney, as seen by the naked eye, and under a low magnifying power. The tubuli uriniferi, in passing outward from the calices, increase in number by divarication, to a considerable extent, as shown in Fig. 69; but their diameter remains the same. When they arrive in the cortical substance, their previously straight direction is departed from, and they become much convoluted. The closeness of the texture formed by their interlacement with the blood-vessels renders it difficult to obtain a clear view of their mode of termination. There seems no doubt, however, that they inosculate with each other, forming a plexus, with a free extremity here and there; but the number of these free or cœcal extremities does not appear to be nearly equal to that of the uriniferous tubes themselves. Scattered through the plexus formed by the blood-vessels and uriniferous tubes, a number of little dark points may be seen with the naked eye, to which the designation of Corpora Malpighiana has been given, after the name of their discoverer. Each one of these, when examined with a high magnifying power, is found to consist of a convoluted mass of minute blood-vessels, somewhat resembling the convolute masses of absorbents termed lymphatic glands. It was at one time supposed, that the uriniferous tubes have their origin in them, but the careful examinations of Müller and Huschke have clearly proved, that the vascular bodies have no direct connection with that system, being only capable of injection from the arteries or veins. Of their use nothing whatever is certainly known; it is evident, however, that they must have some special function, since they are found in the kidneys of nearly all vertebrated animals.

Fig. 70.



Extremity of one of the tubuli uriniferi, from the kidney of an adult; showing its tesselated epithelium.—Magnified 250 Diam. (After Wagner.)

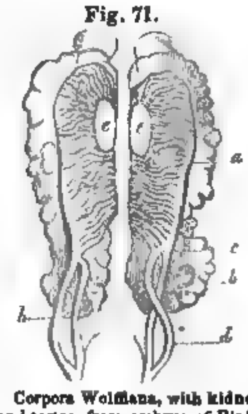
668. The walls of the tubuli uriniferi are evidently the parts in which the secretion takes place. When one of the cœcal extremities is examined with a high power, its mucous membrane is found to be covered with a layer of nucleated cells, forming an epithelium.

669. The embryological development of the Urinary organs in Vertebrated animals is a subject of peculiar interest, owing to the correspondence which may be traced between the transitory forms they present in the higher classes, and their permanent condition in the lower. In this respect there is an evident analogy with the Respiratory system; and it may be remarked that the analogy does not cease here. Both the Urinary and the Pulmonary organs are destined to excrete the products of decomposition, united in their simplest forms of combination;—carbon and oxygen being

thrown off from the lungs or gills, in the form of carbonic acid;—and carbon and nitrogen from the kidneys, in the form of cyanogen, which unites with oxygen to produce cyanic acid, and this combines with ammonia (a compound of nitrogen and hydrogen) to form urea, the characteristic element of the urinary excretion. Both organs, moreover, have the important function of getting rid of the superfluous fluid of the body. Again, it is an interesting fact that, in the *Holothuria* and other animals of its type, the respiration is performed by the introduction of water through a system of branching tubes, that extend from the cloaca into the interior of the body; this system of tubes, considered in regard to its structure and position, is evidently analogous to the urinary apparatus of higher animals. The first appearance of any thing resembling a urinary apparatus in the chick, is seen on the second half of the third day. The form at that time presented by it is that of a long canal, extending on each side of the spinal column from the region of the heart towards the allantois; and the sides of this present a series of elevations and depressions, indicative of the commencing development of cœca. On the fourth day, the *Corpora Wolffiana*, as they then are termed, are distinctly recognized, as composed of a series of cœcal appendages, which are attached along the whole course of the first-mentioned canal, opening into its outer side. On the fifth day, these appendages are convoluted; and the body which they form acquires increased breadth and thickness. They evidently then possess a secreting function; and the fluid which they separate is poured by the long straight canal into the cloaca. Between their component shut sacs, numbers of small points appear, which consist of little clusters of convoluted vessels, exactly analogous to the Corpora Malpighiana of the kidney.

670. The Corpora Wolffiana, however, have only a temporary existence in the higher Vertebrata; although it seems that, in Fishes, they constitute the permanent kidney.* The development of the true Kidneys commences in the chick about the fifth day. They are seen on the sixth, as lobulated grayish masses, which sprout from the outer edges of the Wolffian bodies; and they gradually increase, the temporary organs diminishing in the same proportion. The sexual organs, as will be hereafter explained (§ 699), also originate in the Wolffian bodies; and at the end of fœtal life, the only vestige of the latter is to be found as a shrunk rudiment situated near the testes of the male. The progress of development in the Human embryo seems closely conformable to the foregoing account. The Wolffian bodies begin to appear towards the end of the first month; and it is in the course of the seventh week that the true kidneys first present themselves. From the beginning of the third month, the diminution in the size of the Wolffian bodies goes on *pari passu* with the increase of the kidneys; and at the time of birth scarcely any traces of them can be found. At the end of the third month, the kidneys consist of seven or eight lobes, the future pyramids; their excretory ducts still terminate in the same canal which receives those of the Wolffian bodies

Fig. 71.



Corpora Wolffiana, with kidney and testes, from embryo of Birds; *a*, kidney; *b*, *b*, ureters; *c*, corpus Wolffianum; *d*, its excretory duct; *e*, *e*, testicles; at the summit are seen the supra-renal capsules.

* See Principles of General and Comparative Physiology, § 659.

and of the sexual organs; and this opens, with the rectum, into a sort of cloaca, or sinus urogenitalis, analogous to that which is permanent in the oviparous Vertebrata. The kidneys are at this time covered by the supra-renal capsules, which are very large; about the sixth month, however, these have decreased, whilst the kidneys have increased, so that their proportional weight is as 1 to 2½. At birth, the weight of the kidneys is about three times that of the supra-renal capsules, and they bear to the whole body the proportion of 1 to 80: in the adult, however, they are no more than 1 to 240. The Corpora Wolffiana are, when at their greatest development, the most vascular parts of the body next to the liver; four or five branches from the aorta are distributed to each, and two veins are returned from each to the vena cava. The upper veins and their corresponding arteries are converted into the renal or emulgent vessels; and the lower into spermatic vessels. The lobulated appearance of the kidney gradually disappears; partly in consequence of the condensation of the cellular tissue which connects the different parts, and partly through the development of additional tubuli in the interstices. The urinary bladder is formed quite independently of the secreting apparatus, being a part of the *allantois*, which is first developed as a large cœcum or diverticulum from the lower extremity of the alimentary canal (Chap. XIV). The part of the tube below this forms the cloaca, or common termination of the intestinal and vesical apparatus. The sides of this cloaca, however, gradually approach one another, so as to form a transverse partition, which separates the rectum from the genito-urinary canal; and the urethra of the female is afterwards separated from the vagina by a similar process.

671. The nature and purposes of the Urinary secretion, and the alterations which it is liable to undergo in various conditions of the system, are much better understood than are those of the Bile; this is owing, in great part, to the circumstance, that it may be readily collected in a state of purity, and that its ingredients are of such a nature as to be easily and definitely separated from each other by simple chemical means. There can be no doubt that the chief purpose of this excretion, is to remove from the system the effete azotized matters which the blood takes up in the course of the circulation, or which may have been produced by changes occurring in itself. This is evident from the large proportion of nitrogen which is contained in the solid matter dissolved in it; and from the crystalline form presented by this solid matter when separated,—a form which indicates that its state of combination is such as to prevent it from conducing to the nutrition of the system. The injurious effects of the retention in the blood of the components of the urinary secretion, are fully demonstrated by the results of its cessation; whether this be made to take place experimentally (as by tying the renal artery), or be the consequence of a disordered condition of the kidney. Symptoms of great disorder of the nervous centres, analogous to those produced by many narcotic poisons, soon exhibit themselves; and the patient dies comatose, if the secretion be not restored. In such cases, urea (the characteristic ingredient of the urine) is found to have accumulated in the blood; and it may even be detected by the smell, in the fluid effused into the ventricles of the brain. The conclusion which may be drawn from this circumstance, regarding the pre-existence in the blood of the components of the secretion, is strengthened by the fact that, even in the healthy state, urea may be detected in the blood; it only exists there normally, however, in very small quantity; but, when there is any impediment to its excretion, it goes on accumulating, and produces consequences more or less serious in proportion to its amount. It is not probable that,

as in the case of the retention of bile in the blood (§ 662), many of the minor as well as of the severer forms of sympathetic disturbance, connected with disordered secretion from the kidney, are due to the directly poisonous operation of the elements of the urine, upon the several organs whose function is disturbed.

672. In order to form a correct opinion of the state of the urinary secretion in morbid conditions of the system, it is desirable to be acquainted with every leading particular regarding its healthy characters. The average quantity during 24 hours, has been variously estimated; it differs, of course, with the amount of fluid ingested; and it is influenced also by the external temperature,—a much smaller amount of the superfluous fluid of the body being set free from the skin in winter than in summer, and a larger proportion being carried off by the kidneys. Probably we shall be pretty near the truth, in estimating the amount at about 30 oz. in summer, to 40 oz. in winter, for a person who does not drink more than the simple wants of nature require. The specific gravity comes to be a very important character, in various morbid conditions of the urine: and it is therefore desirable to estimate it correctly. This also is, of course, liable to the same causes of variation; since, when the same amount of solid matter is dissolved in a larger or smaller quantity of water, the specific gravity will be proportionably lower or higher. From long and repeated attention to this subject, Dr. Prout is satisfied that the standard specific gravity of the urine of a healthy person in the prime of life, during the whole year in this country, is something less than 1020, ranging from about 1015 in the winter to 1025 in the summer. The following analysis of healthy urine, by Berzelius, is regarded by Dr. Prout as correctly representing its components.

Animal and destructible principles.	*a.*	Water	933·00
	b.	Urea	30·10
	c.	Lithic acid	1·00
	d.	Free lactic acid, lactate of ammonia, and animal matters not separable from them	17·14
	e.	Mucus of the bladder	0·32
Alkaline and earthy salts.	*f.*	Sulphate of soda	3.16
		——— potash	3·71
	g.	Phosphate of soda	2·94
		——— ammonia	1·65
	h.	Muriate of soda	4·45
		——— ammonia	1·50
	i.	Earthy phosphates, with trace of fluate of lime	1·00
		Silex	·03
			1000·00

673. The most important of all these ingredients is evidently that which, from its being supposed to be the principal cause of the characteristic properties of the urine, is termed *Urea.* This may be readily separated from urine, in the form of transparent colourless crystals, which have a faint and peculiar but not urinous odour. It is very soluble in water, and combines with acids without neutralizing them: in the human urine it is believed to exist in the state of a lactate; whilst in the urine of herbivorous animals it is combined with hippuric acid. In its chemical composition, it is identical with cyanate of ammonia; and its composition is 2 Carbon, 4 Hydrogen, 2 Nitrogen, and 2 Oxygen,—a formula much

more simple than that of almost any other organic substance. The amount of urea excreted in twenty-four hours has been made the subject of examination by Lecanu;* and the following are its results, as deduced from a series of 120 analyses.

	Minimum.	Mean.	Maximum.
By men	357·51 grs.	433·13 grs.	510·36 grs.
By women . . .	153.25	295·15	437·06
By old men (84 to 86 years)	61·08	125·22	295·15
By children of eight years .	161·78	207·99	254·20
By children of four years .	57·28	69·55	81·83

It is very interesting to perceive, in this table, how large an amount of urea is excreted by children; and how small a quantity, in proportion to their bulk, by old men. This corresponds precisely with the rapidity of interstitial change at different periods of life. (See § 646.) Urea is regarded by Dr. Prout as chiefly derived from the decomposition of the gelatinous tissues; but there seems no valid reason thus to limit the mode of its production.

674. The next important ingredient, *Lithic* or Uric Acid, has not been proved to exist in the blood; but it is an invariable constituent of healthy urine, in which it exists in solution at all ordinary temperatures. According to Dr. Prout, however, this acid is not free, but is ordinarily combined with ammonia; and the reddening of litmus paper by urine is not altogether due to it (as commonly supposed), but also to the superphosphate of ammonia, which is also present in the urine. Pure lithic acid is so sparingly soluble in water, that at least ten thousand times its own weight is required to dissolve it. Amongst other proofs that lithic acid does not exist free in urine, is this important one,—that it is precipitated immediately on the addition of a small quantity of any acid, even the carbonic; hence, if a free or imperfectly-neutralized acid exist in the urine, lithic acid will be thrown down as gravel, even though it is not itself present in undue proportion. It is believed by Dr. Prout, that lactic acid, secreted in excess, is the ordinary source of this deposit. The ultimate elements of Uric acid are 10 Carbon, 4 Hydrogen, 4 Nitrogen, and 6 Oxygen; it is considered by Liebig to contain urea ready formed, as will be presently shown.

675. Many remarkable changes are effected in Lithic acid by the operation of other chemical agents; and these changes are very important in their bearing on pathological conditions of the urine. The first that will be noticed is that which gives rise to the peculiar compound termed *Allantoin*, which naturally exists in the fluid of the allantois of the cow, having been secreted by the fœtus. This may be formed artificially by boiling uric acid with peroxide of lead, from which process there result an oxalate of the protoxide of lead, urea, and allantoin; the composition of which last substance is very different from that of urea or uric acid, being 8 Carbon, 5 Hydrogen, 4 Nitrogen, and 5 Oxygen. Upon this reaction, Liebig founds the opinion that uric acid consists of urea in combination with a hypothetic acid analogous to the oxalic, but having cyanogen substituted for its carbon. By the operation of nitric acid upon uric acid several new products are generated, some of which are of much practical interest. To one of these the name of Murexid has been given, on account of its reddish purple colour (resembling that of the Tyrian dye which was obtained from a species of Murex); this is a crystalline substance, sparingly soluble in cold

* Journal de Pharmacie, Tom. xxv.

water, but copiously soluble in warm, imparting to it its vivid colour. By Dr. Prout it was long since described as consisting of a peculiar acid, the purpuric, in combination with ammonia; this view of its composition is not generally received by German Chemists; but it has lately been supported by Fritzsche, who has shown the real existence of the acid by obtaining purpurates of other bases. This substance is one source of the colours of the pink and lateritious sediments, which so often present themselves in the urine: these hues partly depend, however, on the influence of nitric acid upon the peculiar colouring principles of the urine, the nature of which principles is not yet fully understood. Dr. Prout considers that they have an intimate relation to lithic acid on the one hand, and to the colouring matter of the bile on the other.

676. Although the proportion of *Lactic* acid in healthy urine cannot be exactly specified, there is reason to believe that it is considerable. This substance may be referred to the class of saccharine principles, being obtainable from them (as from milk, beet-root, &c.) by fermentation. It is considered by Dr. Prout to result, like urea, from the decomposition of the gelatinous parts of the system; according to Berzelius, however, it is a general product of the spontaneous decomposition of animal matters within the body. Its existence in the blood cannot be clearly demonstrated; although there is reason to believe that it is present in that fluid, in combination with alkaline bases. The relation of lactic acid to sugar, and its influence in precipitating lithic acid, are interesting when considered in reference to the fact of the frequent deposit of lithic acid gravel in diabetic urine. When this occurs, it may be considered a favourable symptom; since it shows that an unnatural product, sugar, has given way, in some degree, to a natural one, lactic acid. On the other hand, the appearance of sugar in urine affording lithic acid deposits, is an unfavourable symptom; showing that a natural product, lactate of urea, has given way to an unnatural one, saccharate of urea. The frequency of lithic acid deposit in conjunction with slight disorders of the digestive system, is well explained by the tendency of such disorders to occasion mal-assimilation of the saccharine principle, in which lactic acid will be produced.

677. In regard to the compounds of phosphoric and sulphuric acids existing in the urine, it is interesting to remark, that these acids do not exist as such in the blood; but that their bases only—sulphur and phosphorus—can be traced, and these in union with its organic constituents. Muriatic acid, on the other hand, exists in the blood in combination with soda and potash; and its salts appear to pass through the kidneys unchanged. The bases with which the phosphoric and sulphuric acids are combined in the urine,—namely, potash, soda, ammonia, lime, and magnesia,—are for the most part uncombined with acids in the blood, but form incidental elements of various organic compounds, from which they can be only obtained by incineration. Hence, as Dr. Prout justly observes, the number of oxidzied and acidified principles found in the urine is very remarkable, and places the function of the kidneys in a striking point of view, more especially when compared with that of the liver, of which the secretion is alkaline, and deficient in oxygenized compounds. The following table is given by Dr. Prout as exhibiting a contrasted view of the relations between the principles of the blood, and the principles of the bile and of the urine, formed either mediately or immediately from the blood. This table is intended to represent the phenomena as they *generally* take place, and not as they *may*, and perhaps *do*, in some instances, take place;—in other words, the law and not the exception. The analogical relations in compo-

BLOOD contains: In *health*.	BLOOD contains: In *disease*.	Represented in the Bile by — BILE contains: In *health*	BILE contains: In *disease*.	Represented in the Urine by — URINE contains: In *health*.	URINE contains: In *disease*.
Water.		Water		Water	
Albumen, equivalent to Gelatine	Urea Sugar		Albumen?	Urea (lactate of)	Carb. of ammonia Sugar Oxalic acid, &c.
Fibrin, equivalent to Albumen	Lithic Acid? Lithate of Soda?	Picromel? Mucus		Lithic acid Lithate of Ammonia Mucus	Purp. of ammonia, &c. Xanthic oxide Cystic oxide Secretion of prostate Pus Prussian blue Indigo, &c.
Hæmatosine Fatty matters	- - - - - -	Colouring matter Biliary resin Colesterine		Colouring matter	Colouring matter of bile Biliary resin Cholesterine
Lactic acid, and its accompanying animal matters, according to Berzelius.		Lactic acid (in combination) and its accompanying animal matters, according to Berzelius.		Lactic acid and its accompanying animal matters, according to Berzelius.	Free lactic acid
Sulphur, phosphorus, fluorine (?) in incidental union with animal matters.		Sulphur, phosphorus, fluorine(?) in incidental union with animal matters.		Sulphuric, phosphoric, and fluoric acids, all in combination as salts.	Sulphur Phosphorus
Muriatic acid in combination as salt.		Muriatic acid in combination, as salt.		Muriatic acid in combination as salt.	
Potash, soda, partly in union with animal matters.		Potash, soda, partly in union with animal matters, and various acids.		Potash, soda, in combination with acids, as salts.	Free alkalies? Alkaline carbonates
Lime, magnesia, silex (?), in incidental union with animal matters.		Lime, magnesia, silex (?) in incidental union with animal matters.		Lime, magnesia, silex (?) in combination with the phosphoric acid.	Lime and magnesia in excess

sition among albumen, gelatine, urea, lithic acid, lactic acid, sugar, oxalic acid, &c., are such, that sugar and oxalic acid (for instance) may be formed from lithic acid as well as from urea. There is greater difficulty in supposing that sugar or lactic acid may be directly formed from gelatine, or that lithic acid may be directly formed from albumen; and yet there is reason to believe that these and many more anomalous conversions may take place.

678. The amount of azotized matter in the urine is greatly influenced by the nature of the food ingested, whilst the constitution of the animal frame remains nearly the same; hence it appears that a large portion of it must be derived from the unassimilated materials which have been taken into the blood, and which, being superfluous, are injurious. From the experiments of Chossat it appeared, that each ounce of dry farinaceous food produced from 16 to 19 grains of solid matter; whilst each ounce of dry albumen produced 73 grains; and each ounce of dry fibrin, 76 grains. He calculated that $\frac{10}{11}$ of all the azote ingested with the food was discharged by the kidney; but this estimate was probably too high. In herbivorous animals, again, the proportion of urea and uric acid is constantly less than in carnivorous. Hence we see the importance of strict adherence to a farinaceous diet, when there is an excessive tendency to the production of these compounds. Uric acid is replaced in some herbivorous animals by the hippuric (containing a comparatively small proportion of nitrogen), the compounds of which are much more soluble than those of the former; and as the latter are produced by the action of benzoic acid upon the urates, it has been proposed to exhibit this, in order to prevent the deposition of gouty concretions, and even to cause them to be redissolved. This plan is stated to have been attended with success.* The fact of the pre-existence of the chief constituents of urine in the blood, is important as explaining the facility with which the secreting function appears to be transferred to other membranes, in some of the cases in which the kidney does not perform its function. Doubtless there has been much error on this subject, arising out of deceptions practised by impostors; but a sufficient number of indubitably genuine cases are on record, to put it beyond doubt that such transferences have taken place,—urinous fluid being secreted from the stomach, mammæ, umbilicus, nose, &c.†

679. The facility with which substances taken into the current of the circulation pass into the urinary secretion, varies extremely; and no general law can be stated in regard to it. It appears from Woehler's elaborate researches on this subject, that the salts which are most readily excreted are those which excite the action of the kidneys.‡ The rapidity with which absorption and elimination take place is often extremely remarkable; prussiate of potash has been detected in the urine within two minutes after it had been introduced into the stomach. For the transit of the peculiar principles of vegetables, however, it appears that from one to two hours are usually required. The effect of oil of turpentine, a d probably of other volatile agents, is produced much more rapidly; the haracteristic odour of violets being perceptible in the urine passed but a few minutes after the vapour of the oil had been received into the lungs.

Mammary Gland.—Secretion of Milk.

680. The structure of the *Mammary* Gland, which has been recently

* Dr. Alex. Ure, in Medico-Chirurgical Transactions, Vol. xxiv.
† For a scientific explanation of this fact, see Princ. of Gen. and Comp. Phys. § 539.
‡ See Müller's Physiology, p. 589.

investigated fully by Sir A. Cooper, is very simple, and easily described. It consists of a series of ducts passing inwards from their termination in the nipple, and then ramifying like the roots of a tree, their ultimate subdivisions terminating in minute cells. The mamillary tubes are usually about ten or twelve in number; they are straight ducts, of somewhat variable size; and their orifices, which are situated in the centre of the nipple, and are usually concealed by the overlapping of its sides, are narrower than the tubes themselves. At the base of the nipple, these tubes dilate into reservoirs, which extend beneath the areola and to some distance into the gland, when the breast is in a state of lactation. These are much larger in many of the lower Mammalia, than they are in the Human female; their use is to supply the immediate wants of the child when it is first applied to the breast, so that it shall not be disappointed, but shall be induced to proceed with sucking until the *draught* be occasioned (§ 426). From each of these reservoirs commence five or six main branches of the lactiferous tubes, each of which

Fig. 72.

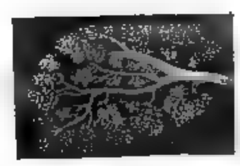
Distribution of the milk-ducts in the Mamma of the human female, during lactation, the ducts injected with wax. (After Sir A. Cooper.)

speedily subdivides into smaller ones, and these again divaricate, until their size is very much reduced, and their extent greatly increased. The proportional size of the trunk and of its branches appears to follow the same law which governs that of the blood-vessels. The breast is not formed into regular lobes by the ramifications of the ducts, because they ramify between, and intermix with, each other, so as to destroy the simplicity and uniformity

of their divisions. It is very rarely, however, that they inosculate. The mammary ducts are composed of a fibrous coat lined by a mucous membrane; the latter is highly vascular, and forms a secretion of its own, which sometimes collects in considerable quantity when the milk ceases to be produced.

681. The gland itself is composed of the union of a number of glandules, which are connected by means of the fibrous or fascial tissue of the gland; it is between these that the mammary tubes may be observed to ramify, and from them their branches spring. When the glandules are filled with injection, and for a long time macerated in water and unravelled, they are found to be disposed in lobuli; and when a branch of a mammary tube is separated, with the glandules attached, the part appears like a bunch of fruit hanging by its stalk. When the lactiferous tube proceeding from a glandule is minutely injected, the latter will be found to be composed of numerous cells, in which the ultimate ramifications of the former terminate, or rather originate. Their size, in full lactation, is that of a hole pricked in paper by the point of a very fine pin; so that the cellules are, when distended with quicksilver or milk, just visible to the naked eye. At other times, however, the cells do not admit of being injected, though the lactiferous tubes may have been completely filled. They are lined by a continuation of the same membrane with that which lines the ducts, and this possesses a high vascularity. The arteries which supply the glandules with blood become very large during lactation; and their divisions spread themselves minutely on the cells. From the blood which they convey, the milk is secreted and poured into the cells, from which it flows into the ducts. No minute examination has yet been made of the parenchyma of the gland; but it is probable that it is composed, like that of the liver, of nucleated vesicular tissue, which may be the real agent in the secretion. Absorbent vessels are seen to arise in large numbers from the milk-cells; their function appears to be, to absorb the more watery part of the milk contained in the cells and tubes, so as to render it more nutrient than it is as first secreted; and also to relieve the distention which would occur, during the absence of the child, from the continuance of the secreting process.

Fig. 73.



Termination of portion of milk-duct in cells; from a mercurial injection, by Sir. A. Cooper; enlarged four times.

682. The Mammary gland may be detected at an early period of fœtal existence; being easily distinguishable from the surrounding parts by the redness of its colour and its high vascularity; especially when the whole is injected. At this period it presents no difference in the male and female; and it is not until near the period of puberty that any striking change manifests itself, the gland continuing to grow, in each sex, in proportion to the body at large. About the age of thirteen, however, the enlargement of the gland commences in the Female; and by sixteen years, it is greatly evolved, and some of the lactiferous tubes can be injected. At about the age of twenty, the gland attains its full size previous to lactation; but the milk-cells cannot even then be injected from the tubes. During pregnancy, the mammæ receive a greatly-increased quantity of blood. This determination often commences very early, and produces a feeling of tenderness and distention, which is a valuable sign (where it exists in connection with others) of the commencement of gestation. The areola at this time becomes darker in its colour, thicker in substance, and more extended; its papillæ become more

developed, and the secretion from its follicles increased.* The vascularity of the gland continues to increase during pregnancy; and at the time of parturition, its lobulated character can be distinctly felt. The cellules are not, however, developed sufficiently for injection, until lactation has commenced. After the cessation of the catamenia from age, so that pregnancy is no longer possible, the lactiferous ducts continue open, but the milk-cellules are incapable of receiving injection. The substance of the glandules gradually disappears, so that in old age only portions of the ducts remain, which are usually loaded with mucus; the place of the glandules is commonly filled up by adipose tissue, so that the form of the breast is preserved. Sir A. Cooper notices a curious change, which he states to be almost invariable with age, —namely the ossification of the arteries of the breast, the large trunks as well as the branches, so that their calibre is greatly diminished or even obliterated.

683. The Mammary gland of the Male is a sort of miniature picture of that of the female. It varies extremely in its magnitude, being in some persons of the size of a large pea, whilst in others it is an inch or even two inches in diameter. In its structure it corresponds exactly with that of the female, but is altogether on a smaller scale. It is composed of lobules containing cells from which ducts arise; and these cells and ducts are not too minute to be injected, although with difficulty. The evolution of the gland goes on *pari passu* with that of the body, not undergoing an increase at any particular period; it is sometimes of considerable size in old age. A fluid, which is probably mucus, may be pressed from the nipple in many persons; and this in the dead body with even more facility than in the living. That the essential character of the gland is the same in the male as in the female, is shown by the instances, of which there are now several on record, in which infants have been suckled by men.† Corresponding facts are also recorded of the male of several of the lower animals.

684. The secretion of Milk consists of water holding sugar, and various saline ingredients, in solution; and in which oleaginous globules, with particles of a form of albumen termed casein, are suspended. Its constitution is made evident by the ordinary process to which it is subjected in domestic economy. If it be allowed to stand for some time, exposed to the air, a large part of the oleaginous globules come to the surface, being of less specific gravity than the fluid through which they are diffused. At the same time, there is reason to believe that they undergo a change, which will

* This change is greatly relied on by many Obstetricians, as an unequivocal Sign of Pregnancy. It is probably one of the best single signs to which the medical man can have recourse, in the early months; but it must not be implicitly relied on. The change of colour varies in degree in different individuals; and *all* the alterations referred to may take place when the uterus is distended by hydatids, fibrinous concretions, &c., as occurred in a well-marked case within the Author's own experience.

† See the case described by the Bishop of Cork, in the Philosophical Transactions, Vol. XLI. p. 813; one mentioned by Captain Franklin (Narrative of a Journey to the Polar Sea, p. 157); and one which fell under the notice of the celebrated traveller Humboldt (Personal Narrative, Vol. III. p. 58). The following is given by Dr. Dunglison (Physiology, Vol. II. p. 439, 4th Ed). "Professor Hall, of the University of Maryland, exhibited to his Obstetrical class, in the year 1837, a coloured man, fifty-five years of age, who had large, soft, well-formed mammæ, rather more conical than those of the female, and projecting fully seven inches from the chest; with perfect and large nipples. The glandular structure seemed to the touch to be exactly like that of the female. This man had officiated as wet-nurse, for several years, in the family of his mistress; and he represented that the secretion of milk was induced by applying the children entrusted to his care, to the breasts, during the night. When the milk was no longer required, great difficulty was experienced in arresting the secretion. His genital organs were fully developed."

be presently described. The cream thus formed does not, however, consist of oily particles alone, but includes a considerable amount of albumen, with the sugar and salts of the milk. These are further separated by the continued agitation of the cream, which separates it into butter, formed by the aggregation of the oily particles, and buttermilk, containing the albumen, sugar, &c. A considerable quantity of albumen, however, is entangled with the oleaginous matter; and this has a tendency to decompose, so as to render the butter rancid. It may be separated by melting the butter at the temperature of 180°; when the albumen will fall to the bottom, leaving the butter pure, and much less liable to change. The milk, after the cream has been removed, still contains the greatest part of its albumen and sugar. If it be kept long enough, spontaneous change takes place in its composition; the sugar is converted into lactic acid, and this coagulates the albumen, precipitating it in small flakes. The same precipitation may be accomplished at any time by the addition of an acid; all the acids, however, which act upon albumen, do not precipitate casein, as will presently be pointed out in detail; the most effectual is that contained in the dried stomach of a calf, known as *rennet*, which exerts so powerful an influence over it, that one part is capable of coagulating 1800 parts of milk. The whey left after the curd has been separated, contains a large proportion of the saccharine and saline matter entering into the original composition of the milk. This may be readily separated by evaporation.*

685. When milk is examined with the microscope, it is seen to contain a large number of particles of irregular size and form, suspended in a somewhat turbid fluid. Of these the most constant are the smooth homogeneous globular particles, which are found by their complete solubility in ether, to consist entirely of oily matter, without any investing membrane. These are the true milk globules. Besides these, there are other globules distinguished by their facette-like appearance, which are stated by some to present themselves only when the fluid has been exposed to the air, although others assert that they may be detected in fresh-drawn milk. The Author's own observations lead him to the belief that the latter of these statements is correct. Besides these particles, there are found in the colostrum, or milk first secreted after delivery, large yellow granulated corpuscles, which are described by Donné as composed of a multitude of small grains enclosed in a transparent envelope, and frequently including a true globule of milk in the centre; these are for the most part soluble in ether. Lamellæ of epithelium are also found in the milk. All these globules may be removed by repeated filtration; and the fluid is then nearly transparent. This, in fact, is the simplest way of separating the oleaginous from the other constituents of the milk; as little albumen then adheres to the former. That the transparent fluid which has passed through the filter contains nearly the whole amount of the casein of the milk, appears a sufficient proof that this is truly dissolved in the fluid, and forms no part of the globules, which some have imagined to consist of it. We shall now consider the chemical characters of each of the foregoing ingredients.

686. The *oleaginous* matter of milk principally consists, like fatty matter in general, of the two substances elaine and stearine, which are converted in the process of saponification into the elaic, stearic, and margaric acids; but it also contains another substance peculiar to it, which yields in saponification three volatile acids, of strong animal odour, to which Chevreul has given the names of butyric, caproic, and capric acids;

* A considerable quantity is thus obtained for household purposes in Switzerland.

whilst the fatty substance itself, to which the peculiar smell and taste of butter are due, is designated as *butyrine*. The peculiar acids are not only formed when the butyrine is treated with alkalies; but are produced by the ordinary decomposition of this principle, which is favoured by time and moderate warmth. The *Casein*, or cheesy matter of milk, which is obtained with some slight admixture of fatty matter in the production of cheese from skimmed milk, is commonly stated to be chiefly distinguished from albumen by the peculiar readiness with which it is precipitated by acetic acid, and by its solubility in an excess of the precipitant. The casein of Human milk, however, is much less precipitable by acids than is that of the cow; very commonly resisting the action of the mineral acids, and even that of the acetic; but being always coagulated by rennet, though the curd is long in collecting. It is remarked by Dr. G. O. Rees,* that the casein of human milk thus bears somewhat the same relation to that of the cow, that the albumen of chyle bears to that of the blood. The *Sugar* of milk, which may be obtained by evaporating whey to the consistence of a syrup and then setting it aside to crystallize, contains a large proportion (12 per cent.) of water, so that it may be considered as really a hydrate of sugar; it is nearly identical in its composition with starch, and may, like it, be converted into true sugar by the action of sulphuric acid. It is interesting to see the close approximation to the vegetable character, which this important element of the secretion presents. The *Saline* matter contained in milk appears to be nearly identical with that of the blood, with perhaps a larger proportion of the phosphates of lime and magnesia, which amount to 2 or 2½ parts in 1000.

687. It is very interesting to observe that Milk thus contains the three classes of principles which are required for human food—the albuminous, oleaginous, and saccharine; and it is the only secreted fluid in which these all exist in any considerable amount. It is, therefore, the food most perfectly adapted for the young animal; and it is the only single article supplied by nature, in which such a combination exists. Our artificial combinations will be suitable to replace it, just in proportion as they imitate its character, but in none of them can we advantageously dispense with milk, under some form or other. It should be remembered that the saline ingredients of Milk, especially the phosphates of lime and magnesia, have a very important function in the nutrition of the infant,—affording the material for the consolidation of its bones; and any fluid substituted for milk, which does not contain these, is deficient in essential constituents. It is very justly remarked by Dr. Rees, that, of all the secreted fluids, Milk is most nearly allied in its composition to blood; and the following table expresses the parallelism of the several ingredients. The correspondence between the fibrin and albumen of the blood, and the casein† of the milk, needs no explanation. That of hæmatosine and fatty matter is less evident; but there are many chemical relations between them. It is not easy to obtain hæmatosine quite free from fatty matter; on the other hand, the fatty matter of the colostrum has frequently a deep red tinge. The sugar of milk is probably derived from the aqueous extractive of the blood, which is considered by Berzelius to contain the debris of the various

* Art. Milk, in the Cyclopædia of Anatomy and Physiology, from which many of the chemical details in the text are derived.

† It is suggested by Dr. Rees, that the casein of the fibrin may be that which is entangled with the oily globules to form cream, whilst it is the casein of the albumen which remains in solution. If this be true, there would be no inconsiderable analogy between the process of creaming and the coagulation of the blood.

decomposing tissues, that have been taken up in the course of the circulation; these seem to have a tendency to return to the crystalline form; and, from what has been formerly stated of the relation of sugar to the animal tissues (§ 613), this would appear to be one of their most ready modes of re-combination.

	BLOOD.	MILK.	
Coagulum	Fibrin	Casein	*Cream.*
	Red particles	Butyraceous matter	
Serum	Albumen	Casein	*Skim Milk.*
	Alcoholic extractive; viz. lactates	Alcoholic extractive; viz. lactates and lactic acid	
	Aqueous extractive; albuminate of soda	Aqueous extractive, with sugar of milk	
	Alkaline salts	Alkaline salts	
	Fatty matter	Fatty matter	

688. The proportion of the different ingredients in the Milk of different animals is subject to considerable variation; and this fact is of much practical importance in guiding our selection, when good Human milk cannot be conveniently obtained for the nourishment of an infant. The first point to be inquired into is the quantity of solid matter contained in each kind; this may be determined either by evaporation, or by the specific gravity of the fluid. The Specific Gravity of Human milk is stated by Dr. Rees to vary between 1030 and 1035; others, however, have estimated it much lower. That of the Cow appears to be usually about 1030; that of the cream being 1024, and that of the skimmed milk about 1035. The variation will in part depend (as in the case of the urine) upon the quantity of fluid ingested, and in part, it is probable, upon the manner in which the milk is drawn; for it is well known to milkers, that the last milk they obtain is much richer than that with which the udder is distended at the commencement. The quantity of solid matter, obtainable from Human and from Cow's Milk by evaporation, seems, like the specific gravities of the fluids, to be nearly the same, varying from 11 to 12½ per cent. In the relative proportions of the ingredients, however, there is a considerable difference, there being much more butter and less casein in Human Milk than in that of the Cow; so that the former would be most nearly represented by the cream of the latter, mingled with about half its proportion of skim milk, and the other half water. The cream of Human Milk has been found by Sir A. Cooper to vary in proportion to the milk, from one-fifth to one-third of the whole volume; the largest amount being given by well-fed women, free from mental anxiety, and at an early period after parturition. It is curious, however, that, although it diminishes to as little as one-seventh between the fourth and ninth months of lactation, it increases again between the twelfth and the eighteenth, being sometimes, at the latter period, almost a third of the whole. In conformity with this change in the character of the secretion, it is found that the specific gravity increases during the early weeks, as the oleaginous part gives place to the albuminous and saccharine. The following table exhibits the relative proportion of the different ingredients in the milk of various animals from which it is commonly obtained. It appears from this, that, whilst the milk of the Cow, Goat, and Sheep do not differ from each other in any very prominent degree, that of the Ass and Mare is a fluid of very dissimilar character, containing a comparatively small proportion of casein and butter, and abounding in sugar. Hence it is

that it is much more disposed to ferment than other milk; indeed the sugar of Mare's milk is so abundant, that the Tartars prepare from it a spirituous

	Woman.	Cow.	Goat.	Sheep.	Ass.	Mare.
Casein	2·50	4·48	4·02	4·50	1·82	1·62
Butter	5·18	3·13	3·32	4·20	·011	traces
Sugar of Milk and aqueous extractive	6·52	4·77	5·28	5·00	6·08	8·75
Saline matters . .		0·60	0·58	0·68	0·34	89·63
Water	85·80	87·02	86·80	85·62	91.65	

liquor, to which they give the name of *koumiss*. It appears from these details that no milk more nearly approaches that of the Human female, than that of the Sheep and Goat; these both possess, however, a larger proportion of casein, which forms a peculiarly dense curd; and the milk of the Goat is tainted with the peculiar odour of the animal, which is more intense if the individual be dark coloured. The milk of the Cow will usually answer very well for the food of the infant; care being taken to dilute it properly, according to the age of the child.

689. The change which naturally takes place, from the condition of colostrum to that of true milk, during the first week of lactation, is a very important one. The colostrum has a purgative effect upon the child, which is very useful in clearing its bowels of the meconium that loads them at birth; and thus the necessity of any other purgative is generally superseded. Occasionally, however, the *colostric* character is retained by the milk, during an abnormally long period; and the health of the infant is then severely affected. It is important to know that this may occur, even though the milk may present all the usual appearance of the healthy secretion; but the microscope at once detects the difference.* The return to the character of the early milk, which has been stated to take place after the expiration of about twelve months, seems to indicate that Nature designs the secretion no longer to be encouraged. The mother's milk cannot then be so nutritious to the child as other food,† and every medical man is familiar with the injurious consequences, to which she renders herself liable by unduly prolonging lactation.‡

690. From what has been stated of the close correspondence between the elements of the Blood and those of the milk, it is evident that we can scarcely expect to trace the existence of the latter, as such, in the circulating fluid. To what degree the change, in which their elaboration consists, is accomplished in the Mammary gland, or during the course of the circulation, there is no certain means of ascertaining. The recent discovery of the usual presence of the organic compound named *kiestine* (which is nearly related to casein), in the urine of pregnant women, seems to indicate that the conversion of albumen into casein takes place in the blood,—this curious excretion being the means of preventing its accumulation in the circulating fluid, previously to the time when it is secreted by the mammæ.§

* See Donné, "Du Lait, et en particulier celui des Nourrices;" and Brit. and For. Med. Review, Vol. vi. p. 181.

† On the whole subject of Infant Nutrition, the Author would strongly recommend the excellent little work of Dr. A. Combe, formerly referred to.

‡ One of these, which has particularly fallen under the Author's notice, is debility of the retina, sometimes proceeding to complete amaurosis; this, if treated in time, is most commonly relieved by discontinuance of lactation, generous diet, and quinine.

§ See Dr. Golding Bird, in Guy's Hosp. Rep. Vol. v.

It is evident that this secretion cannot serve as the channel for the deportation of any element, the accumulation of which would be injurious to the system; since it does not occur in the male at all; and in the female at particular times only. Yet there is reason to believe that if, whilst the process is going on, it be suddenly checked, the retention of the material in the blood, or the re-absorption of the secreted fluid, is attended with injurious consequences. Thus if, when the milk is first secreted, the child be not put to the breast, an accumulation takes place, which, if not relieved, occasions great general disturbance of the system. The narrowness of the orifices of the milk-tubes obstructs the spontaneous exit of the fluid, especially in *primiparæ;* the reservoirs and ducts become loaded; further secretion is prevented; and a state of congestion of the vessels of the gland, tending to inflammation, is induced. The accompanying fever is partly due, no doubt, to the local disturbance; but in part also, there seems reason to believe, to the re-absorption of the milk into the blood: this cannot but be injurious, since, although but little altered, the constitution of milk is essentially different, especially in regard to the quantity of crystallizable matter (sugar) which it contains. The instances of the vicarious secretion of milk are not numerous; and in no instance is there any proof that the elements of the fluid were pre-existent in the blood. Some of the most curious are those, in which it has been poured out from a gland in the groin, but it is probable that this was in consequence of the existence of a real repetition, in that place, of the true mammary structure,—this being the situation of the mammæ of many of the inferior animals, of which the analogues in Man are usually undeveloped.

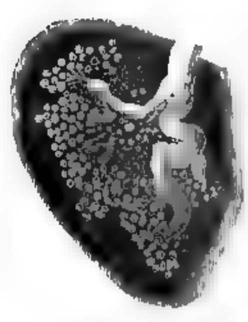
691. The following is a more unequivocal case of vicarious secretion; and it is peculiarly interesting as exhibiting the injurious effects of the re-absorption of the secretion, and the relief which the system experienced when it was separated from the blood by the new channel. "A lady of delicate constitution (with a predisposition to pneumonia) was prevented from suckling her child, as she desired, by the following circumstance. Soon after her delivery she had a severe fever, during which her breasts became very large and hard; the nipples were swollen and firm, and there was evidently an abundant secretion of milk; but neither the sucking of the infant, nor any artificial means, could draw a single drop of fluid from the swollen glands. It was clear that the milk-tubes were closed; and as the breasts continued to grow larger and more painful, purgatives and other means were employed to check the secretion of milk. After three days the fever somewhat diminished, and was replaced by a constant cough, which was at first dry, but soon after was followed by the expectoration of simple mucus. After this, the cough diminished in severity, and the expectoration became easy; but the sputa were no longer mucous, but were composed of a liquid, which had all the physical characters of genuine milk. This continued for fifteen days; the quantity of milk expectorated amounting to three ounces or more in the twenty-four hours. The breasts gradually diminished in size; and, by the time that the expectoration ceased they had regained their natural dimensions. The same complete obstacle to the flow of milk from the nipples recurred after the births of four children successively, with the same sequelæ. After the sixth, she had the same symptoms of fever, but this time they were not followed by bronchitis or the expectoration of milk; she had in their stead copious sweatings, which with other severe symptoms reduced her to a cachectic state, and terminated fatally in a fortnight."*

* Bulletino delle Scienze Mediche, Apr. 1839; and Brit. and For. Med. Review, Jan. 1840.

692. Of the quantity of Milk ordinarily secreted by a good Nurse, it is impossible to gain any definite idea; as the amount which can be artificially drawn affords no criterion of that which is secreted at the time of the *draught* (§ 426). The quantity which can be squeezed from either breast at any one time, and which, therefore, must have been contained in its tubes and reservoirs, is about two ounces. The amount secreted is greatly influenced by the physical and mental condition of the female, and also by the quantity and character of the ingesta. In regard to the influence of the mental state upon this secretion, ample details have already been given (Chap. VII.) With respect to the physical state most favourable to the production of an ample supply of this important fluid, it may be stated generally, that sound health, a vigorous but not plethoric constitution, regular habits, moderate but not fatiguing exercise, and an adequate but not excessive amount of nutritious food, furnish the conditions most required. It is seldom that stimulating liquors, which are so commonly indulged in, are anything but prejudicial; but the unmeasured condemnation of them in which some writers have indulged, is certainly injudicious, as experience amply demonstrates the improvement in the condition of both mother and infant, which occasionally results from the moderate employment of them. The influence of various medicines upon the milk is another important question, which has not yet been sufficiently investigated. As a general rule, it appears that the most soluble saline compounds pass into the milk as into other secretions; but there are many exceptions. Common salt, the sesqui-carbonate of soda, sulphate of soda, iodide of potassium, oxide of zinc, tris-nitrate of bismuth, and sesqui-oxide of iron, were readily detected in the milk, when these substances were experimentally administered to an ass; and ordinary experience shows that the human infant is affected by many of these when administered to the mother. The influence of mercurial medicines taken by the mother, in removing from the infant a syphilitic taint possessed by both, is also well known. The vegetable purgatives, especially castor oil, senna, and colocynth, have little effect upon the milk; hence they are to be preferred to the saline aperients when it is not desired to act upon the bowels of the child.

Salivary Glands and Pancreas.

Fig. 74.



Lobule of Parotid gland of a new-born infant injected with mercury. Magnified 50 Diam.

693. The structure of the *Salivary Glands* and *Pancreas* in Man bears considerable resemblance to that of the Mammary glands. In some of the lower tribes, however, they are much simpler. Thus, in the Echinodermata and in Insects, the Salivary glands have the character of prolonged cœca, more or less convoluted; and the Pancreas of Fishes presents itself in the form of a cluster of short cœca round the pyloric extremity of the stomach, and opening into it by distinct orifices. The accompanying figure will give a sufficient idea of the structure of these glands in Man; the cells are very minute, having a diameter only about three times greater than that of the capillary blood-vessels. Their development commences from a simple canal, sending off bud-like processes, which opens from the mouth, and lies amidst a vesicular blastema. As development proceeds, the canal becomes more and more ramified, increasing at the expense of the blastema, which is at last almost wholly absorbed; so that the sub-

stance of the gland consists of the ducts with their ramifications and cellular terminations, and of the blood-vessels which are distributed upon these.

694. The Salivary secretion is by no means necessarily constant, being almost or completely suspended by cessation of the movement of the masticator muscles and tongue, if unexcited by any nervous stimulus. Hence it is that the secretion is checked during sleep; so that, if the mouth be kept open, its surface is almost dried up by the atmosphere. The mode in which the secretion is excited through the influence of the nervous system has already been considered (§§ 425,6). The quantity of saliva formed during the twenty-four hours, has been estimated at about 15 or 20 ounces; but on this point it is evidently impossible to speak with certainty. The fluid obtained from the mouth is of a more viscous character than the true saliva secreted by the glands, being mingled with mucus. The salivary fluid varies as to its chemical re-action; being sometimes slightly acid, and sometimes slightly alkaline; but it is never precisely neutral. It has been stated to be alkaline at meal-times, but acid at other periods; on this point, however, there is still much room for inquiry. Its specific gravity varies from 1·006 to 1·009. It contains a small number of corpuscles, which partly seem to be epithelium-cells. The solid matter contained in Saliva is estimated by Berzelius at about 1 per cent. The animal principles of which this is composed are osmazome, mucus, and a peculiar substance termed salivary matter, which is soluble in water, insoluble in alcohol, and yet is different either from albumen or gelatine. Clear Saliva, when submitted to the influence of galvanism, is found to exhibit a faint coagulum; and hence it has been supposed to contain albumen. The presence of this substance, however, is doubtful. A considerable proportion of saline and earthy matter exists in the solid residue of saliva; this is nearly of the same character as that which the blood contains, being chiefly composed of the phosphate of lime and soda, the chlorides of sodium and potassium, and the lactates of soda and potash. One remarkable property of the salivary secretion, is its formation of a rust-red precipitate, when mixed with a solution of a per-salt of iron. This is supposed to be due to the presence in it of the principle termed sulpho-cyanogen. The tartar which collects on the human teeth consists principally of the earthy phosphates, the particles of which are held together by about 20 per cent. of animal matter; and nearly the same may be said of the salivary concretions which occasionally obstruct the ducts.

695. The Pancreatic Secretion of Man cannot, of course, be readily obtained for analysis; that which is procured from the lower animals, however, probably gives a sufficiently correct idea of its character. It seems to be of a nearly similar nature with saliva, but contains a much larger proportion of solid matter; in that of the dog as much as 8·72 has been found, and in that of the sheep between 4 and 5 per cent. In the pancreatic fluid of the horse, on the other hand, the quantity of solid matter seems to be less than in the saliva. Of the residuum obtained by evaporation, half appears to consist of albumen; there is also a small amount of osmazome, and apparently of casein. A free acid, probably the acetic, exists in this fluid; the salts which it contains are nearly the same as those of the saliva.

Lachrymal Gland.

696. The *Lachrymal* glands and their secretion may be next mentioned; but neither require any lengthened description. The gland in Man is formed very much on the plan of the Parotid, being composed of branched canals

terminating in cells, the ultimate ramifications of the several branches forming lobules or divisions of the glands. The lachrymal fluid has not recently undergone any accurate analysis; and all that can be stated respecting it is the general fact, that the quantity of solid matter in it is extremely small, and that this consists chiefly of saline, and either mucous or albuminous compounds. It seems probable that the secretion of the lachrymal gland itself is very little else than the serum of the blood deprived of great part of its albumen; and that the mucus of the tears is secreted from the surface of the conjunctival membrane. This secretion has a slightly alkaline reaction. It is being constantly formed in moderate amount, for the purpose of cleansing the surface of the eye from the impurities which would otherwise rest upon it; and it is then absorbed by the open orifices of the nasal duct, and carried into the nose, as fast as it is poured out. The cause of this absorption does not seem very clear. Capillary attraction is probably in part concerned; and it has been thought that the momentary partial vacuum occasioned by the inspiratory effort in all the air-passages, will cause the emptying of the nasal duct below, and a consequent in-draught above. The influence of the nervous system upon this secretion has been already adverted to (§§ 425, 6).

The Testis.—Spermatic Fluid.

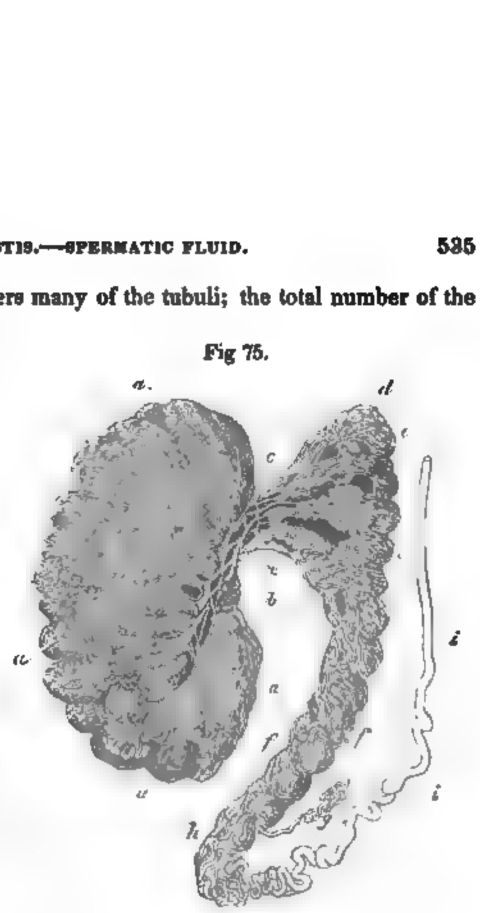
697. In the Testes we turn to the tubular form of glandular structure, which so remarkably distinguishes the kidney from all the other glands hitherto mentioned. The external forms presented by these glands throughout the Animal kingdom, are extremely various; but their composition is for the most part very uniform. The object is sometimes attained by a simple but much elongated canal; sometimes by shorter branched tubes; and in other instances, again, by numerous aggregated cœca, which are often rounded into cells. In regard to this, as to many other glands, it may be stated that, whilst its general form in Insects is that of prolonged tubes, the required extension of surface is given in the Mollusca by the multiplication of cells, so that the structure has a compact spongy character. It is interesting to remark that, in some of the lowest Fishes, this organ consists of a mass of cells which have no efferent ducts; and that the secretion formed within these escapes by the rupture of the cells, which allows it to escape into the abdominal cavity, whence it passes by openings that lead directly to the exterior. In these Fishes, the ova are discharged from the ovarium in a very similar manner; a modification of which plan is followed in all the higher Vertebrata,—the ovum being in them also discharged by the rupture of its containing vesicle or ovisac, into the abdominal cavity, but immediately received and conveyed away by the funnel-shaped internal prolongation of the external orifice, which is known as the fimbriated extremity of the Fallopian tube.*

698. The Testis in Man has in every respect, however, a distinctly glandular character. It consists of several lobules, which are separated from each other by processes of the tunica albuginea that pass down between them, and also by an extremely delicate membrane (described by Sir A. Cooper under the name of tunica vasculosa) consisting of minute ramifications of the spermatic vessels united by cellular tissue. Each lobule is composed of a mass of convoluted tubuli seminiferi, throughout which blood-vessels are minutely distributed. The lobules differ greatly in size,

* See Principles of General and Comparative Physiology, § 641.

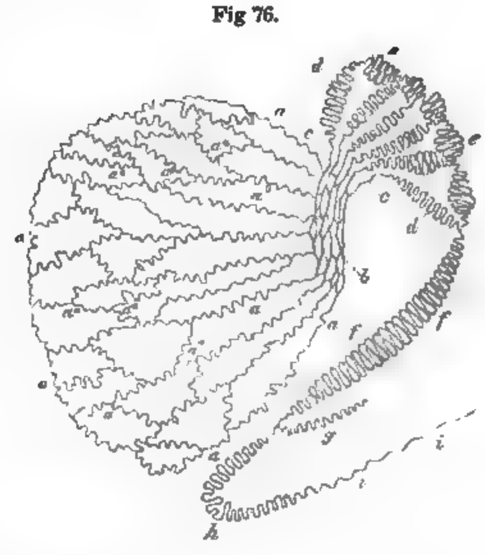
some containing one, and others many of the tubuli; the total number of the lobules is estimated at about 450 in each testis, and that of the tubuli at 840. The convolutions of the tubuli are so arranged, that each lobule forms a sort of cone, the apex of which is directed towards the rete testis. It is difficult to trace the free extremities of the seminiferous tubes, owing to the frequency of their anastomoses with each other; in this respect, therefore, the structure of the testis accords closely with that of the kidney. The diameter of the tubuli seminiferi is for the most part very uniform; in the natural condition they seem to vary from about the $\frac{1}{180}$th to the $\frac{1}{170}$th of an inch; but when injected with mercury they are distended to a size nearly double the smaller of these dimensions. When they have reached to within a line or two of the rete testis, they cease to be convoluted, several unite together into tubes of larger diameter, and these enter the rete testis under the name of *tubuli recti*. The *rete testis* consists of from seven to thirteen vessels, which run in a waving course, anastomose with each other, and again divide, being all connected together. The *vasa efferentia* which pass to the head of the epididymis are at first straight, but soon become convoluted, each forming a sort of cone, of which the apex is directed towards the rete testis, the base to the head of the epididymis. The number of these is stated to vary from nine to thirty, and their length to be about eight inches. The *epididymis* itself consists of a very con-

Fig 75.



Human testis, injected with mercury as completely as possible; *a*, *a*, lobules formed of the seminiferous tubes; *b*, rete testis; *c*, vasa efferentia; *d*, flexures of the efferent vessels passing into the head; *e*, *e*, of the epididymis; *f*, body of the epididymis; *g*, appendix; *h*, cauda; *i*, vas deferens. (After Lauth.)

Fig 76.



Plan of the structure of the testis and epididymis; *a*, *a*, seminiferous tubes; *a**, *a**, their anastomoses; the other references as in the last figure.

voluted canal, the length of which is about twenty-one feet. Into its lower extremity, that is, the angle which it makes where it terminates in the vas deferens, is poured the secretion of the *vasculum aberrans* or appendix, which seems like a testis in miniature, closely resembling a single lobule in its structure. Its special function is unknown.

699. The Testicles originate, in the embryo, from the lower part of the Corpora Wolffiana (§ 670); arising from their lower and inner sides, whilst the kidneys spring from their upper and outer parts. They make their first appearance in the Chick about the fourth day, as delicate striæ on the Wolffian bodies; and at this period no difference can be detected between the Testes and the Ovaria, which originate in precisely the same manner. Like the kidneys, the germ-preparing organs increase in proportion with the diminution in the temporary structures; at first their efferent ducts open into those of the Wolffian bodies, but they are subsequently separated by the formation of a partition, like that which separates the rectum from the cloaca. In the Human embryo, the rudiments of the sexual organs,—whether testes or ovaria,—first present themselves soon after the kidneys make their appearance, that is, towards the end of the seventh week. They are at first much prolonged, and seem to consist of a kind of soft, homogeneous blastema, in which the tubular structure subsequently developes itself. The ovary at that period has the same aspect and texture; but its subsequent course of development is different. The testis gradually assumes its permanent form; the epididymis appears in the tenth week; and the gubernaculum, (a membranous process from the filamentous tissue of the scrotum, analogous to the round ligament arising from the labium, and attached to the ovary of the female,) which is originally attached to the vas deferens, gradually fixes itself to the lower end of the testis or epididymis.* The testes begin to descend at about the middle period of pregnancy; at the seventh month they reach the inner ring; in the eighth they enter the passage; and in the ninth they usually descend into the scrotum. The cause of this descent is not very clear. It can scarcely be due merely, as some have supposed, to the contraction of the gubernaculum; since that does not contain any fibrous structure until after the lowering of the testes has commenced. It is well known that the testes are not always found in the scrotum at the time of birth, even at the full period. Upon an examination of 97 new-born infants, Wrisberg found both testes in the scrotum in 67,—one or both in the canal in 17,—in 8 one testis in the abdomen, and in 3 both testes within the cavity. Sometimes one or both testes remain in the abdomen during the whole of life; but this circumstance does not seem to impair their function. This condition is natural, indeed, in the Ram.

700. The fluid secreted by the Testes is thick, tenacious, and of a grayish or yellowish colour. It is mingled, during or before emission, with fluid secreted by the prostate, Cowper's glands, &c.; and it cannot, therefore, be obtained pure, but by drawing it from the testicle itself; hence no accurate analysis can be made of it. The Spermatozoa and seminal granules, which form the most important and characteristic parts of the Semen, can scarcely be regarded as products of secretion, and will be described under another head. The peculiar odour which the Semen possesses does not appear to belong to the spermatic fluid, but is probably derived from

* Mr. Mayo mentions (Physiology, p. 530) a curious malformation that came under his notice, which is explained by this fact. The left testis had not descended, and lay upon the edge of the psoas muscle immediately within the internal ring; while the cord was drawn down into the scrotum through the persistence of the original attachment of the gubernaculum, forming a long loop.

one or other of the secretions with which it is mingled. The chemical analyses which have been made of this fluid are all defective, inasmuch as they do not distinguish the real secretion of the testes from the mucus, prostatic fluid, &c., with which it is mingled. It may be stated, however, that it has an alkaline reaction, and contains albumen, with a peculiar animal principle termed spermatine; and also saline matter, consisting chiefly of muriates and phosphates, especially the latter, which form crystals when the fluid has stood for some little time.

Cutaneous and Mucous Follicles.

Fig. 77.

Sudoriferous gland from the palm of the hand, magnified 40 Diam.; *a*, *a*, contorted tubes, composing the gland, and uniting into two excretory ducts, *b*, *b*, which unite into one spiral canal, that perforates the epidermis at *c*, and opens on its surface at *d*; the gland is imbedded in fat-vesicles, which are seen at *e*, *e*. (After Wagner.)

701. Having now described the structure and functions of the principal Glands which are composed of aggregated masses of secreting cells or tubes, we may proceed to those in which the *glandulæ* are more scattered, but are still, in their aggregate amount, of sufficient importance to claim particular notice. This is especially the case in the Skin, and its internal prolongations, forming Mucous Membranes. The skin is the seat of various secretions,* for each of which it is provided with special organs. Of these the most important is the Perspiration, which is formed in small glandular organs seated just beneath the cutis, and diffused over the whole surface of the body. The efferent ducts of these glandulæ open by minute pores in the epidermis, which are seen in elevated lines on the skin of the palm of the hand and the sole of the foot; they penetrate the epidermis rather obliquely, so that a sort of little valve is formed by it, which is lifted up by the excreted fluid as it issues. The ducts pass through the epidermis and cutis in a spiral direction, and then enter the glands, which consist of the convolutions of the ducts, more or less subdivided, on which blood-vessels are distributed. Where the epidermis is thin, the canal is straighter. The secretion of fluid by these glands is continually taking place; but this fluid, being usually carried off in the form of vapour as fast as it is separated, does not accumulate and become sensible. If, however, from the increased amount of the secretion, or from the condition of the surrounding air, the whole fluid thus poured out should not evaporate, it accumulates in minute drops upon the surface of the skin. Thus the sudoriferous excretion may take the form either of sensible or insensible transpiration; the latter being constant, the former occasional.

* The epidermis and its appendages, hair, nails, &c., have been commonly regarded in this light, but are now to be viewed very differently.

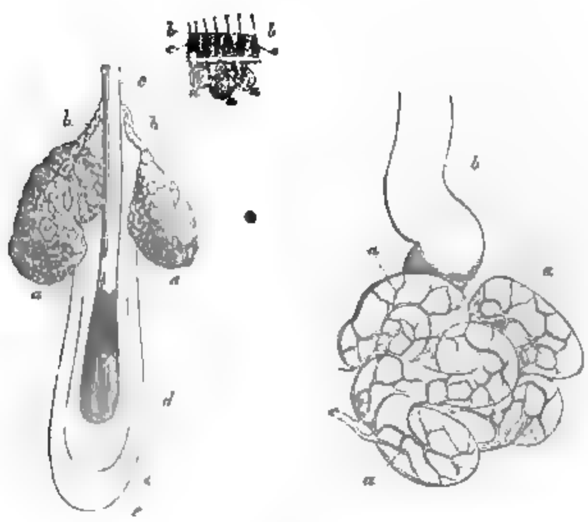
It is difficult to obtain enough of this secretion for analysis, free from the sebaceous and other matters which accumulate on the surface of the skin; and its character can only, therefore, be stated approximatively. It has usually an acid reaction, which seems due to the presence of lactic acid; and to this we are probably to attribute the sour smell which it has, especially in some disordered states of the system. In other respects it seems to correspond pretty closely with saliva,—containing osmazome with saline matter, especially chloride of sodium and muriate of ammonia. The proportion of solid matter contained in it cannot be estimated with readiness. It appears, however, that of the whole amount of fluid which passes off from the surface of the skin, only a small proportion can be properly said to be secreted by the sudoriferous glands; the greater part, under ordinary circumstances, being the product of simple evaporation, by which, of course, nothing but pure watery vapour is dissipated.

702. The whole amount of fluid which is insensibly lost from the cutaneous and pulmonary surfaces, is estimated by Seguin at 18 grains per minute; of which 11 grains pass off by the skin, and 7 by the lungs. The maximum loss by exhalation, cutaneous and pulmonary, during twenty-four hours, (except under very peculiar circumstances,) is 5 lbs.; the minimum $1\frac{2}{3}$lb. It varies greatly, according to the condition of the atmosphere, and that of the body itself. The manner and degree in which it is influenced by atmospheric conditions, will be better discussed under the head of Animal Heat; since this influence has a most important effect in the regulation of the temperature of the body. Its variation according to the state of the bodily system is such, that it tends to reduce the body every day to nearly the same standard of weight; making up the difference, as it were, between the weight of the other egesta and that of the ingesta. The urinary secretion being the one chiefly concerned in draining the body of its superfluous fluid, the cutaneous exhalation is thus in great degree vicarious with it, increasing with its diminution, and diminishing with its increase. The exhalent action of the skin is influenced, also, by general conditions of the vascular and nervous systems, which are as yet ill understood. It is quite certain, however, that through the influence of the latter the secretion may be excited or suspended; this is seen on the one hand in the state of syncope, and in the effects of depressing emotions, especially fear, and its more aggravated condition, terror; and on the other in the dry condition of the skin during states of high nervous excitement. It is very probable that, in many forms of fever, the suppression of the perspiration is a cause, rather than an effect, of disordered vascular action; for there are several morbid conditions of large parts of the surface, in which the suppression of the transpiration appears to be one of the chief sources of danger, having a tendency to produce congestion and inflammation of internal organs.

703. The skin is likewise furnished with numerous Sebaceous glands, also distributed more or less closely throughout the whole surface of the body. Some of these are simple follicles contained in the substance of the skin itself; whilst others are formed out of similar follicles, more or less branched, elongated, and convoluted; these last commonly open into the passage by which the hair makes its way outwards. Besides these, there are other glands situated in particular parts of the body, and having special functions. Such are the Ceruminous glands situated beneath the skin of the auditory meatus; these are closely analogous in form to the sudoriferous glands, as the accompanying figure shows; but their secretion is very different, being nearly solid, and having somewhat of a resinous character. It is probable that by similar glands are elaborated the odorous secretions,

which are exuded from particular parts of the surface, especially the axillæ. In many of the lower animals, such glands may be detected, having a structure of considerable complexity. The odorous secretion would appear to

Fig. 78.



Cutaneous glands of external meatus auditorius. A. Section of the skin, magnified three diameters, *b*, *b*, hairs; *c*, *c*, superficial sebaceous glands; *a*, *a*, larger and deeper-seated glands, by which the cerumen is secreted. B. A hair, perforating the epidermis at *c*; *a*, *a*, sebaceous glands, with their excretory ducts *b*, *b*; *d*, base of the hair, in its double follicle, *e*, *e*. C Cerumen-gland, formed by the contorted tube, *a*, *a*, of the excretory duct, *b*; *c*, vascular trunk and ramifications.—The last two figures highly magnified. (After Wagner.)

be elaborated from the blood by a simple chemical change; for it may be made evident, even in blood that has been dried up, by treating it with sulphuric acid. This aromatic principle differs sufficiently in the blood of different animals, to enable a person with a delicate sense of smell to determine from what animal any specimen has been procured; and this fact has been applied with success to juridical investigations. It has even been stated that the blood of the human Male may be distinguished from that of the Female by its more powerful odour; but this does not appear to be the case,—at least with sufficient certainty for medico-legal inquiries.*

704. Besides the *crypts* or follicles, which have been spoken of as generally existing in Mucous Membranes, there exist, in that of the intestinal canal, numerous glandulæ in various parts, for the elaboration of particular secretions. In the stomach, for example, a large number of these secreting organs, some of them possessing rather a complex structure, are included in the thickness of its walls, composing indeed the greater part of the mucous membrane. If this be divided by a section perpendicular to its surface it is seen to be made up of a number of tubuli closely applied to each other, their blind extremities being in contact with the submucous tissue, and their open ends being directed towards the cavity of the stomach. In

* See Annales d'Hygiene, Vol. i pp. 267 and 548; Vol. ii. p. 217; Vol. x. p. 160, &c.

Fig. 79.

A

B

Section of the coats of the stomach, near the pylorus, showing the gastric glands. A, magnified three times. B, magnified twenty times. (After Wagner.)

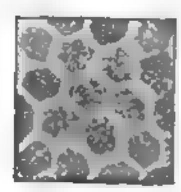
some situations these tubuli are short and straight; in other parts they are longer, and present an appearance of irregular dilatation, or partial convolution. This indeed is their usual character, especially towards the cardiac orifice of the stomach. On the other hand, towards the pyloric extremity they have a much more complex structure. Between the tubuli, blood-vessels pass up from the submucous tissue, and form a vascular network on its surface. From the examination of these horizontal sections of the mucous membrane at various depths, Dr. Todd* has ascertained that the tubuli are arranged in bundles or groups, surrounded and bound together by a fine cellular membrane; the size of the bundles, and the number of tubules contained in them, vary considerably. The tubes do not, in general, open directly upon the surface, but into the bottom of small depressions or cells, which may be seen to cover the membrane. These cells are more or less circular in form, and are separated from one another by partition-like elevations of the membrane, which vary in depth; and sometimes even by pointed processes, that have been mistaken by some anatomists for villi. The diameter of the cells varies from about 1-100th to 1-250th of an inch; it is always greater near the pylorus. When the surface of the membrane, cleansed from mucus and epithelium-scales, is examined with a sufficient magnifying power, it is seen that from three to five perforations exist in the floor of each cell; and these are the openings of the secreting tubes. The gastric fluid, elaborated by this apparatus, having been already made a subject of special consideration (§ 434, et seq.) need not be here described.

Fig. 80.

B A

Glands in the coats of the stomach, magnified 45 diameters. A. Gastric gland from the middle of the stomach B. Another of more complex structure, and appearing to contain mucus, from the neighbourhood of the pylorus. (After Wagner.)

Fig. 81.



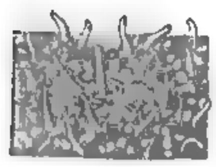
Portion of the mucous membrane of the stomach, showing entrances to the secreting tubes, in cells upon its surface. (After Boyd.)

705. The whole mucous surface of the Intestinal canal is furnished with glandular follicles of a very similar character; of which some approach those of the stomach in complexity of structure, whilst others evidently correspond with the *crypts* of ordinary Mucous Membrane. An innumerable multitude

* Gulstonian Lectures on the Physiology of the Stomach, in Medical Gazette, 1839. See also Dr. Sprott Boyd's Inaugural Dissertation on the Mucous Membrane of the Stomach, in Edinb. Med. and Surg. Journal, Vol. XLVI.

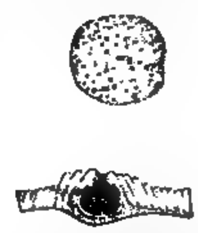
of pores are easily seen, by the aid of a simple lens, to cover the whole internal surface of the large intestine; and these are the entrances to tubular follicles closely resembling those of the stomach, but more simple in structure. Their cœcal extremities abut against the submucous tissue; towards the end of the rectum, however, they are much prolonged, and constitute a peculiar layer between the mucous and muscular coats; the tubes, which are there visible to the naked eye, being erect, parallel, and densely crowded. These glands probably form the peculiarly thick and tenacious mucus of the large intestine. In the small intestine, on the other hand, the cœca are less deep, and their apertures are smaller. These apertures are, for the most part, situated around the bases of the villi; in the fœtus and newly-born child, they are so abundant as to be almost in contact; but in the adult, the intervals increase so as to occupy more space than the apertures. The glandulæ of the small intestine have long been known, under the name of the follicles of Lieberkühn; they become particularly evident when the mucous membrane is inflamed, being then filled with an opaque whitish secretion, which is absent in the healthy state. Besides the foregoing descriptions of solitary

Fig. 82.



Mucous coat of small intestines as altered in fever; the follicles of Lieberkühn filled with tenacious white secretion. (After Boehm.)

Fig. 83.



One of the glandulæ majores simplices, viewed from above, and seen in section; from the large Intestine. (After Boehm.)

glandulæ, the cœcum and the lower part of the rectum contain a number of simple and large follicles, which produce slight rounded elevations on the surface of the mucous membrane; the centre of each of these elevations is perforated by an aperture of the follicle; and around this are seen the orifices of the tubular cœca, which closely envelope the globular follicle. These seem most abundant where the largest quantity of mucus is required. They have been confounded with the glands of Brunner, and with the solitary Peyerian glands presently to be noticed.

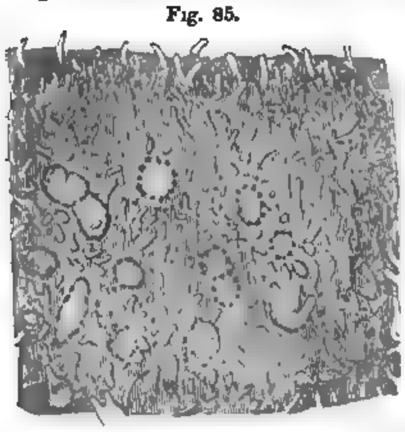
706. The true glands of Brunner are chiefly situated in the Duodenum; and they lie, not in the mucous, but in the submucous tissue, where they form a continuous layer of white bodies surrounding the whole intestine. Their size, unless diseased, is scarcely that of a hemp-seed; each consists of numerous minute lobules, of which the ducts open into a common excretory tube; and in the lobules may be distinguished the minute ramifications of these ducts, with clusters of cells, forming acini, of which about six hundred are computed to exist in each. Hence these glands are of complex structure, much resembling that of the salivary glands and pancreas, and entirely differing from all the other glandulæ of the walls of the alimentary canal. Of the peculiar nature of their secretion nothing is known. The subject of the intestinal secretions generally has been already adverted to (§ 443).

Fig. 84.

Conglomerate gland of Brunner, from commencement of duodenum; magnified a hundred times. (After Boehm.)

707. The so-called Peyerian glands constitute, when aggregated together, large patches on the mucous membrane of the small intestine, where they are known as the *glandulæ agminatæ*; and it is to these alone that Peyer's name is usually applied. Similar bodies, however, exist separately in the lower part of the small intestines, where they have been confounded with the glands of Brunner, which do not extend beyond the commencement of the jejunum. The glands of Peyer, when examined in a healthy mucous membrane, present the appearance of circular white slightly-raised spots, about a line in diameter, over which the membrane is usually less thickly set with villi, and very often entirely free from them. Each of these white spots, of which a large number are contained in the agminated glands, is surrounded by a zone of openings like those of Lieberkühn's follicles, which lead, as do those, into tubular cœca. On rupturing the surface of one of the white bodies, there is found beneath it a cavity, corresponding in extent with the spot, and of considerable depth; but this cavity has no excretory opening; and the tubular follicles, by which it is surrounded have no connection with it. The cavity contains a grayish-white mucous matter, interspersed with granules which are smaller than the ordinary particles of mucus. The membrane which covers in the cavity is extremely thin, and is very liable to be destroyed by ulceration; hence it is that, after inflammation of the membrane, the patches of Peyer are seen as a congeries of shallow open cells or follicles. The use of these bodies is entirely unknown.*

Fig. 85.



Portion of one of the patches of Peyer's glands, from the end of the ileum, highly magnified; the villi are also displayed. (After Boehm.)

The Spleen, and Supra-Renal Capsules.

708. It remains for us to consider certain other bodies, which, from their having a somewhat glandular aspect, are usually ranked among the secreting organs; but which have neither excretory ducts, nor any thing that can be considered as truly glandular in their structure. Of these, the largest and most important in the adult is the Spleen. This organ is essentially composed of a fibrous membrane, which forms its exterior, and which traverses its substance in irregular partitions, leaving a number of cells that communicate with one another. These cells contain a pulpy substance, which consists of a mass of reddish-brown granules,† about the

* For more minute details regarding the structure of the intestinal glands, see the Dissertation of Dr. Boehm, "De Glandularum Intestinarium Structura penitiori," of which an abstract will be found in the British and Foreign Medical Review, Vol. i. (1836), and also in Mr. Solly's work already referred to; {also Prof. Horner's observations, which were published in the American Journal of the Medical Sciences—May, 1835.}

† These corpuscles are described by Mr. Gulliver, (Appendix to Gerber's General Anatomy, p. 102,) as mostly globular, but often oval, some of them containing a nucleus, whilst others appear to be formed simply by an aggregation of granules. They are more unequal in size, and slightly larger, than the blood-discs; their diame-

size of the corpuscles of the blood, but differing from them in form, being irregularly globular and not flattened; they are easily separable from each other. In the mass which they form, the minute arteries ramify in tufts; and they terminate in a very large plexus of venous canals, of which the walls are so thin, that the veins appear as if simply channelled out from the pulpy tissue. From the channels of the veins, a number of small passages may be traced, leading into cells, which can be filled with venous blood from the trunk. In the spleen of many of the lower Mammalia, though much less abundantly in that of Man, are found some grayish-white, globular corpuscles, varying in diameter from $\frac{1}{6}$th of a line to a line, and so soft as to take a liquid form when raised on the knife. These have been described as Malpighian corpuscles; but the particles to which that designation is appropriate are much more minute (being from $\frac{1}{7}$th to $\frac{1}{4}$th of a line in diameter) and of much greater firmness. These are connected together, sometimes in rows, sometimes in bunches, by delicate fibres, which are prolonged from the splenic artery, and are stated by Müller to be minute branches of it; their ramifications pass over the surface of the corpuscles rather than into their interior, which is occupied by irregularly-globular particles, resembling those of the red pulpy substance.

709. In regard to the functions of the Spleen, great uncertainty exists. That it is not an ordinary gland is evident from the absence of an excretory duct; and there is no valid reason to believe that any secretion is formed by it, although some have supposed that the lymphatics, which are abundantly distributed through the organ, might afford a means of exit to the elaborated fluid. That the Spleen performs no function essential to life, has been repeatedly proved by the experimental removal of it in many of the lower animals, and by the accidental loss of it in Man, of which several cases are on record; for after the immediate effects of the wound were recovered from, the vital functions were performed with no perceptible interruption, and health appeared to be completely restored. The apparent restriction of the Spleen to Vertebrated animals, in which it almost invariably exists, and the conjoint restriction of a separate absorbent system to this sub-kingdom, has led to the opinion that the function of the two are in some way connected; but for this there seems no other evidence. Moreover, it is by no means certain that something analogous to a Spleen does not exist in some Invertebrata: this, at least, would seem to be the character of a curious cellular organ which exists in connection with the venous system in many Cephalopoda, and for which no definite function can be assigned.* The theory of the operation of the Spleen, most satisfactory to the Author, is that which regards it as a sort of diverticulum or reservoir, which may serve to relieve the portal venous system from undue distention, under a great variety of circumstances. This system is well known to be destitute of valves; so that the splenic vein has free communication with the whole of it. Hence the Spleen will be a ready diverticulum for the venous blood, when the secreting action of the liver is feeble, so that the portal circulation receives a partial check (§ 662). That any cause of congestion of the portal system peculiarly affects the Spleen, has been proved by experiment; for after the portal vein has been tied, the spleen of an animal, which previously weighed only 2 oz., has been found to weigh a pound and a quarter, or ten times as much. Now it is evident that congestion of the portal system is liable to occur when the alimentary canal is distended with food; and this from two

ter varies from 1-1777th to 1-6000th of an inch, the average being about 1-3038th. These corpuscles may be seen in blood drawn from the Splenic vein.

* Cyclopædia of Anatomy, Vol. I. Art. Cephalopoda.

causes,—the pressure on the intestinal veins, and the quantity of fluid absorbed by these veins. Hence it may be conceived that the Spleen, by affording a reservoir into which the superfluous venous blood may be directed, serves an important purpose in preventing congestion of other organs. From the observations of Mr. Dobson,* it appears that the spleen has its maximum volume at the time when the process of chymification is at an end,—namely, about five hours after food is taken; and that it is small and contains little blood seven hours later, when no food has been taken in the interval. Hence he inferred that this organ is the receptacle for the increased quantity of blood, which the system acquires from the food, and which cannot, without danger, be admitted into the blood-vessels generally; and that it regains its previous dimensions, after the volume of the circulating fluid has been reduced by secretion. This view is confirmed by the fact noticed by several observers,—that the spleen rapidly increases in bulk after the ingestion of a large quantity of fluid, which is absorbed rather by the veins than by the lacteals. It has been further stated in support of this theory, that animals from which the spleen has been removed, are very liable to die of apoplexy if they take a large quantity of food at a time; but that if they eat moderately and frequently, they do not suffer in this manner. The use of the Spleen as a diverticulum for the internal venous circulation, is further borne out by its liability to become enlarged in consequence of intermittent fever; during the cold stage of which, a great quantity of blood is driven from the surface towards the internal organs; and it may be easily imagined that, if there were no such reservoir, the congestions in these would be much more dangerous than those which actually do occur. The permanent enlargement of the organ is of course, on this idea of its use, a result of its frequent distension. That the function of the Spleen is in some way connected with that of Digestion, appears from the fact of the small size of this organ in the fœtal state.

710. The Supra-renal Capsules, like the kidneys, consist of two distinct kinds of substance,—a cortical and medullary. The cortical substance is of a yellowish colour, and consists of straight parallel fibres arranged side by side. Of these straight fibres, a large part are branches of arteries which enter this body at every point of its exterior, from a capillary network covering its surface; and others are corresponding branches of veins that receive the blood from these arteries, and convey it into a venous plexus, of which the medullary substance is chiefly composed. By the union of the veins of this plexus, is formed the large central vein of the organ; and this is the only cavity which it contains. No apparatus of secreting tubes or cells can be detected in it; and its function is entirely unknown. The interspaces of the vessels are filled up by a sort of pulp, which, according to Mr. Gulliver (Op. cit. p. 103), is composed of very minute oil-like spherules, very unequal in their size, varying from 1-24000th to 1-6000th of an inch in diameter, their average size being about 1-10000th. These spherules are but little affected by chemical reagents, and their nature is very uncertain. In many Ruminant animals, the minute spherules are less plentiful, their place being supplied by corpuscles that somewhat resemble lymph globules in size, but are often of a reddish colour, and occasionally of an oval figure. These are sometimes found in the Human subject also, particularly in early life. The blood of the supra-renal vein has been observed to contain numerous minute spherules, which cannot be distinguished from those of the gland; similar particles, however, may be detected in the blood of other parts; and the identity of these is still a

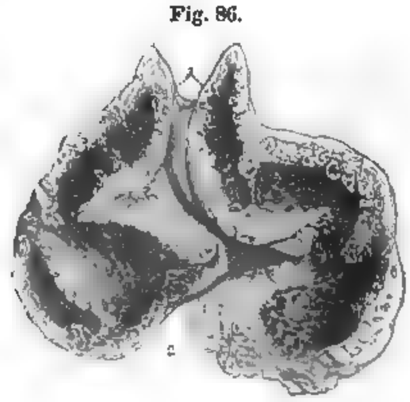
* London Medical and Physical Journal, Oct. 1830.

matter of doubt. The Supra-renal capsules, as already mentioned (§ 670), attain a large size very early in fœtal life, surpassing the true kidneys in dimension up to the tenth or twefth week. As is the case in the spleen, the lymphatics are of large size; these terminate in the lumbar glands. Their arteries are derived from the aorta, the renal, and the phrenic; their veins open into the vena cava on the right side, and into the renal vein on the left. The only use that can be assigned to them with any probability, is that of serving as a means of conveying into the veins the blood transmitted through the renal artery; when from any cause the secreting function of the kidneys is partly or entirely checked, and their capillary circulation in consequence stagnated. This idea seems to derive confirmation from the fact, that these organs have proportionably the largest size during the development of the kidneys; when their secreting function can scarcely be supposed to have commenced.

Thymus and Thyroid Glands.

711. The Thymus Gland, also, is largest in the fœtus, in proportion to the size of the body; but it continues to grow after birth, and remains of considerable size during the first year, after which it gradually diminishes, and wholly disappears about the time of puberty. According to the accurate examination of its structure, recently made by Sir A. Cooper, it is composed of lobules which may be drawn out and separated from one another, in the manner of a string of beads, when their enveloping capsule has been removed. These lobules vary in size from that of the head of a pin, to that of a pea; in their usual position, they are disposed around a large central cavity or reservoir. When a thin slice is cut from one of the lobules, a number of small cells are seen in it; and these are filled with a white granular fluid. The cells open into a cavity at the base of each lobule; and the cavities of the different lobules are connected by a channel, which passes from one to the other, and which has occasioned openings leading into a common reservoir. This reservoir, however, has no efferent duct; and no means of exit can be detected for its contents, except that afforded by the lymphatics, which are large, and terminate directly in the vena cava; their immediate connection with the cavities of the gland has not, however, been demonstrated. The fluid of the Thymus Gland is whitish, having the appearance of chyle or cream; it contains a large number of corpuscles, which are described by Mr. Wilson,* as being "smaller than the blood-corpuscles,

Fig. 86.



A section of the thymus gland at the eighth month, showing its anatomy; from a preparation of Sir A. Cooper's. 1. The cervical portions of the gland; the independence of the two lateral glands is well marked. 2. Secretory cells seen upon the cut surface of the section; these are observed in all parts of the section. 3, 3. The pores or openings of the secretory cells and pouches; they are seen covering the whole internal surface of the great central cavity or reservoir. The continuity of the reservoir in the lower or thoracic portion of the gland with the cervical portion, is seen in the figure.

* Human Anatomy, p. 557.

globular and oval in form, irregular in outline, variable in size, and provided with a small central nucleus. Mr. Gulliver considers them identical (as Hewson did long ago) with the globules which are found in the lymphatics and lacteal vessels after they have passed through the glands; and which are especially abundant in the mesenteric glands during digestion. In the Human fœtus this fluid has been only found by Sir A. Cooper in a quantity too small to be submitted to chemical analysis; but from the thymic fluid of the Calf, which exists in great abundance, the following results were obtained. One hundred parts of the fluid contained sixteen of solid matter; and this consisted of incipient Fibrin, Albumen, Mucus and Muco-extractive matter, Muriate and Phosphate of Potassa, Phosphate of Soda, and a trace of Phosphoric acid.

712. Of the nature of the function of the Thymus Gland, nothing is certainly known. By Hewson it was regarded as an appendage to the system of lymphatic glands; and this doctrine is advocated by Mr. Gulliver. It is remarked by Müller, that it appears quite vain to attempt to explain by hypothesis how the organ can contribute to the formation of the blood in the fœtus and child; and that "every hypothesis which regards it as an organ adapted to the necessities of fœtal life, and not to those of the child, must be incorrect." This last observation appears to be pointed at the theory not long since put forth by Mr. Tyson,* that the office of the Thymus is to receive during fœtal life the blood which is afterwards sent to the lungs; yet in support of this theory something may still be said. It is well known that, although the respiratory function is established at birth, it does not for some time come into full activity. The lungs are small in proportion to the size of the body; the amount of oxygen consumed is much less than in the adult state; and the power of generating heat is comparatively feeble (§ 728). During infancy and childhood, the digestive apparatus is undergoing rapid development, but the lungs do not make the same comparative progress. About the period of puberty, however, their evolution becomes much more rapid, and their function more energetic: so that, at this time, as is well known, disorders of their function, leading to structural changes, are more common than at any other period of life. Now the disappearance of the Thymus Gland, *pari passu* with the evolution of the lungs, does appear to indicate that there is something vicarious or reciprocal in their function. Moreover, it has been shown that one of these vascular masses somewhat resembling glands in structure, but having no secreting ducts, is found in connection with the two other principal excretory organs,—the liver and the kidneys. It may be said, however, in reply, that the lungs do not receive their principal supply of blood from the arterial system, but from the venous, so that, although the two organs are in proximity, there is no direct vascular connection between them. This objection, however, has less force when it is remembered, that up to the time of birth,—the period during which the Thymus gland is of greatest proportional size,—little or no blood proceeds to the lungs through the pulmonary arteries; but that they are then chiefly, if not entirely, supplied by the bronchial arteries; and these come off from the thoracic aorta at no great distance from the internal mammary arteries, which supply the Thymus gland, and are the lowest branches of the subclavian. It is through the bronchial arteries that the blood is conveyed, on which the nutrition of the Lungs depends, during the whole of life; and the history of the development of these organs, compared with that of the Thymus gland, seems to indicate that, just as the flow of

* London Medical and Surgical Journal, 1833.

blood through the one diminishes, that which takes place through the other increases. It is, however, also true (as remarked by Mr. Gulliver) that the Thymus gland diminishes in proportion to the diminished activity of the general nutritive functions; and that its fluid decreases, and becomes less rich in globules, when the supply of food is insufficient, or the animal is prevented by other causes (such as over-fatigue) from duly assimilating it. At present, the question of the specific use of this body must be left in uncertainty.

713. The *Thyroid* Gland appears to have a structure analogous to that of the Thymus; but less is known respecting it. When incised, small cells may be detected in it; but no connection has yet been traced between them, nor is there any common reservoir. Like the Thymus, this body has no excretory duct, but is provided with large lymphatics, which directly enter the great veins.* Though proportionally larger in the fœtus than in the adult, it remains of considerable size during the whole of life, and is supplied with large arteries. The fluid which the cells contain is viscid and nearly colourless, sometimes having a yellowish tinge; when put into rectified spirit, it becomes solid but not opaque; and it probably contains, therefore, some modification of albumen. The Thyroid body is the seat of that enlargement of the neck, which is known as goître or bronchocele. In the commencement of this disease, there seems at first to be simply distension of the cells resulting from increased secretion; so that when the body is cut into, no change of structure is observed in it but such as results from the enlargement of the cells, which are of various sizes, usually from that of a pea downwards, and are filled with a more or less viscid fluid. In more advanced cases, however, other alterations are commonly met with, resulting probably from the altered vascular action generated by the primary affection; so that, when the tumour is cut into, steatomatous, cartilaginous, or even ossific deposits are found in it.

CHAPTER XIII.

GENERAL REVIEW OF THE NUTRITIVE PROCESSES, WITH PRACTICAL APPLICATIONS.—ANIMAL HEAT.

714. The detailed survey which has been now taken, of the different Functional operations concerned in maintaining the life of the individual, may suggest to us some general views that have important practical applications. In the first place, it has been shown, that the province of the Animal is not to combine inorganic elements into organic compounds, fit to be applied to the purposes of nutrition; but to use those which are prepared for it by the Plant. The nutritive materials thus obtained may be divided into two great classes, the azotized and the non-azotized. The former have been shown (§ 454) to be so nearly identical in composition with the proximate principles of which the Animal body is composed, that no great amount of *chemical* transformation can be required to prepare them for being appropriated by it. The latter seem very different in character; and yet it would appear, from several facts, that a transformation of them into

* See King, in Guy's Hospital Reports, Vol. I.

azotized compounds may take place, so that Animals may be supported for some time upon aliment belonging to the saccharine or oily groups. Now there are two opposite states of the system, both indicated by abnormal conditions of the urinary excretion (for these conditions can only be regarded, in a sound Pathology, as indicative of more general disorder), in which there is a disturbance of the due relation between the azotized and the non-azotized elements of the body. In one of these, known as the "gouty or lithic acid diathesis," the tendency to the production of azotized compounds, which, by their decomposition, set free large quantities of urea and lithic acid, seems to be excessive; and the consequence is, that there is not only a very abnormal amount of these compounds in the urine, but, the kidneys not being able to separate them entirely from the blood, deposits of lithic acid take place in other parts, attended with symptoms of a very severe kind, which are doubtless referrible to the disordered condition of the blood. On the other hand, in the "diabetic or saccharine diathesis," there appears to be an inability on the part of the system to effect the due conversion of the non-azotized into the azotized principles; and even in the decomposition of the latter, there is an undue tendency to the production of sugar rather than of urea, which seems to indicate that they have been imperfectly assimilated in the first instance. Now, over both these forms of disease, a careful regulation of the diet exercises a powerful control. A patient affected with the gouty diathesis may palliate, if not altogether cure, his disorder, by rigorously abstaining from the use of azotized compounds as food, and by subsisting entirely upon those belonging to the saccharine group, especially those various forms of farinaceous matter, which are so abundantly yielded by the Vegetable kingdom. Ordinary wheaten bread contains so large a proportion of gluten, that it must be ranked under the proscription; and rice, sago, arrowroot, or potatoes, should be substituted for it. It is by no means every case, however, that is capable of alleviation by treatment of this kind; in fact, it can seldom be rigorously enforced, except in early life, or at any rate when the constitution is unbroken by disease or intemperance. Not unfrequently it will be found, that the exclusive employment of a vegetable diet occasions so much disorder of the stomach, as to be quite out of the question.—The results of some late investigations on the exclusive employment of azotized principles as articles of diet, in the treatment of saccharine diathesis, appear to be nearly as favourable. The plan was long since proposed by Dr. Rollo; and when the diseased condition has not been complicated by other maladies (as is not unfrequently the case), the rigorous enforcement of such a diet has been attended with success in numerous instances. One of the greatest difficulties in the application of the system, however, has arisen from the longing which the patients experience for vegetable food; since this tempts them to gratify their appetites, to the complete prejudice of the remedial system,—a very small amount of farinaceous matter being sufficient to cause the re-appearance of the Sugar, after it seemed to be entirely got rid of. It has been recently proposed by M. Bouchardat to gratify this longing to a certain degree, by allowing the use of bread made of wheaten flour, from which nearly all the fecula has been separated,—the gluten only being left, with such a small amount of fecula as may serve to make it *rise* in fermentation; so that it is as free from unazotized constituents as the average of animal substances. This plan is stated to have been very successfully practised.*

715. The alimentary materials, reduced by the digestive process, are

* See Comptes Rendues de l'Academie Royale, 1841.

first converted, as we have seen, into the form of *Albumen;* and this serves as the pabulum from which are elaborated those compounds, that actually form part of the organized structure. Reason has been given for the belief that Albumen, as such, does not enter into the composition of the solid tissues, and that it never possesses properties which can be distinguished from those of ordinary *chemical* compounds. But, whilst circulating through the vessels of the living body, a change is gradually produced in this principle; its particles seem to undergo a new arrangement, without any essential modification of their state of chemical combination; and it manifests properties altogether different from those of any mere physical agent, and therefore deserving of the appellation *vital.* In this state it is known as *Fibrin;* the difference of which from Albumen essentially consists in its tendency to undergo organization. The coagulation of Fibrin, whether in the blood or in organizable lymph, is the first step in the process; and the degree to which it is carried depends, as has been shown, on the proximity of a living surface (§ 559). Albumen enters into the composition of most of the secretions, without undergoing any considerable alteration; and it is probable that the *Gelatin* also, which forms so large a proportion of the solid matter of the body, is elaborated from it. Reason has been given for the belief that the gelatinous part of the tissues is not in a state of organization (or at any rate possesses but a very imperfect structure), being merely deposited in the cells, tubes, or areolæ, which are left by the network of the fibrinous tissues; the same is to be said of the oily constituents of fat, and also of the mineral ingredients of the hard parts. The conversion of the Albumen into Fibrin, therefore, is an essential step in the process of assimilation; and, if the vital powers of the system be too low to effect this, the albumen accumulates in an excessive degree, and is liable to be deposited in an unorganized state, forming what is known as tubercular matter (§ 609), or to find its way into the urine, at the same time involving disease of the kidney. Hence the essence of what is termed the "strumous diathesis" may be regarded as a low condition of those vital powers, which are concerned in the conversion of the Albuminous materials prepared by the digestive process, into the Fibrinous matter which is ready for assimilation; so that, by a perversion of the ordinary nutrient actions, albuminous tubercle is deposited in the interstices of the tissues, instead of these tissues being themselves regenerated by organizable fibrin; and the same may take place in a more rapid manner, in consequence of that disturbance of the nutrient processes, which is known in healthy constitutions as Inflammation. It is obvious, then, that the treatment of the strumous diathesis should be directed towards the invigoration of the general powers of the system; and although, when disease of the chest has once established itself, a warm damp atmosphere may be necessary as a preventive of inflammatory affections, it is a great mistake to imagine that such a plan is applicable to those in whom there is merely a strumous predisposition; for this should be combated by such means as are calculated rather to brace than to relax the system, especially out-door exercise, nutritious diet, and an airy and well-ventilated habitation. There can be no doubt that the tuberculous cachexia is encouraged, and even developed, by injudicious management during the early ages of life, in many cases where it might have been avoided.* The frequent connection, now very generally recognised, between deficient respiration and albuminuria, seems,

* See the excellent works of Sir James Clark, in which the importance of hygienic treatment is strongly insisted on.

in conjunction with numerous other phenomena, to indicate that the latter disease is rather of constitutional than of local origin, and must be treated accordingly. The abnormal quantity of albumen which is found in the blood in this disease (§ 595), appears of itself a sufficient evidence in favour of this view. Hence the deposition of granular matter in the kidney, and the degeneration of its proper structure, will come to be regarded as only a consequence of the state of the blood peculiar to the disease; just as the substitution of tubercular deposit for organized or organizable matter in the lungs, is but a manifestation of the scrofulous diathesis, the real character of which is to be looked for in the disordered condition of the assimilating processes.

716. From what has been stated in Chap. IX, respecting the nature of the Function of Circulation, it is evident that primary disorders of that function are not nearly so frequent as they are ordinarily supposed to be; and that the proximate cause of morbid phenomena is seldom to be found in them. By the action of the heart and blood-vessels, the nutrient fluid which has been prepared from the alimentary materials submitted to the digestive apparatus, is conveyed to the tissues which it is to nourish; but the true process of Nutrition is independent of this, and may take place after the motion of the fluid has ceased, just as it commences before any movement shows itself. For the tissue which exists in the embryo, during the early period of its developement, and also in any newly-forming part, is destitute of vessels, consisting only of cells; and these grow and reproduce themselves at the expense of the nutritive materials supplied to them from without, just as does the whole mass of a Cellular Plant. Moreover it has been shown (§ 511), that the activity of the nutrient processes has much to do with the movement of the fluid through the smaller vessels, and is a cause rather than a consequence of it. If the action of the heart cease, the whole circulation must obviously come to a stand ere long: but in many animals the capillary movement may continue for some time after the general circulation has been checked; and, so long as blood is supplied to the parts, so long may their nutrition continue, provided other circumstances be favourable. It is unquestionably true, that the cessation of the circulation is usually the immediate cause of *Death;* and that when the suspension is permanent, the loss of the vitality of the system, considered both as a whole, and as made up of distinct parts, is a necessary consequence. But still, we find that the cause of this cessation seldom originates in the circulating apparatus itself. The two chief modes of Death are Syncope and Asphyxia. In the former, the circulation comes to a stand, simply through want of power in the propelling organs to move the blood; this want of power may result from a variety of causes. Long-continued deficiency in the quantity, or depravation of the quality, of the blood, may have induced insufficient nutrition of the heart; and its muscular power may thus be gradually lost. This is a very common mode of Death, as a sequence of exhausting disease. More commonly, however, the cessation of the heart's action is sudden, and results from some impression propagated to it through the nervous system; thus mental emotion, sudden loss of blood, concussion of the nervous centres, injuries extensively involving the nervous ramifications, &c., seem to have an immediately-depressing effect on the heart's action; and in many of these cases, the circulation is checked not merely at the centre but also at the periphery,—the vitality of the system at large, and of the blood, being equally affected with that of the heart (§ 583). The heart's action *may* be checked by causes whose action is purely local; as appears from Mr. Blake's experiments for-

merly referred to (§ 491). But it is probably seldom, in any ordinary condition of the system, that such local action can occur; and a disturbed state of the circulation is therefore to be generally looked upon rather as a result than as a cause of diseased action. An extreme case of such a disturbance, which, when sufficiently prolonged, is attended with fatal results, is to be found in Asphyxia; in which the cessation of the action of the lungs induces a stagnation of the blood in their capillaries; and as, in warm-blooded animals, the whole current of blood has to pass through the lungs, before proceeding again to the system, a total suspension of the circulation necessarily results from this interruption (§§ 508 and 546–8). Now if we take this (which it appears reasonable to do) as a type of a great number of morbid conditions of different organs, we are led to see why a serious disturbance of the movement in any one part should affect the entire circulating apparatus, and should thus influence its flow through almost every other organ. There are no other organs, however, in which a stagnation can be so serious as in the lungs; since there are none through which the whole current flows. The liver ranks next in importance, since all the venous blood collected from the chylopoietic viscera passes through it; and every practical man is aware how frequently derangement of the circulation through the liver, originating in an unhealthy state of the gland itself, is a cause of serious disorders in the abdominal viscera. Minor irregularities in the circulation, in various parts, not unfrequently become causes of serious inconvenience. Thus, few conditions are more common, especially amongst persons of active minds but inert habits, than undue determination of blood to the head, conjoined with torpor of the circulation through the skin, especially that of the extremities, which are ordinarily cold. The obvious indication here is, to endeavour to restore the balance of the circulation; and excitement of the flow of blood through the skin, by frictions, moderately-stimulating applications, exercise, &c., will commonly prove of great utility.

717. There are many disorders commonly regarded as affections of the Circulation, which evidently consist in reality of a morbid alteration in the Nutritive processes; among these there can be little doubt that we are to rank Inflammation. Much has been said and written, to very little purpose, respecting the essential nature of this process; it has been attributed by some to disordered action of the vessels, and by others to an injurious impression on the nerves,—the fact, that inflammation may occur in tissues which contain neither vessels nor nerves, having been entirely overlooked. The only view of the character of Inflammation that seems likely to account for its phenomena, is that which regards it as essentially consisting in a disturbance of the due relation between the living tissue and the nutrient materials contained in the blood. As to the nature of this disturbance, we know no more than we do of the nature of the relation itself; and the expression must, for the present, have somewhat of a vague and indefinite character. Nevertheless, it is much better to have a dim vision of the true beacon, than to be led astray by the more attractive glare of false lights; and whilst the specious hypotheses, which profess to make the whole subject easy of comprehension, are found to be more fallacious, the more they are examined into,—the one just adverted to becomes more satisfactory, the more it can be connected with precise data. That there must be a certain relation or adaptiveness, between the substance of the tissues, and the materials at whose expense they are formed, appears sufficiently evident. It has been pointed out that the albumen of the blood is converted, during its circulation, into fibrin; and that the fibrin is withdrawn, and assimilated by the solid parts. In the tuberculous cachexia, it has been shown that the fibrin is deficient, and that the

tissues are consequently nourished but imperfectly, whilst unorganizable albumen is deposited amongst them. On the other hand, in the inflammatory diathesis, there is probably an increased tendency in the blood to the generation of fibrin; and this, by disturbing the due relation between the nutritive fluid and the solid tissues, may become a cause of local disease,—the morbid action which results from this condition of the blood being determined to a particular part by some extraneous causes. In this morbid action, fibrinous matter is effused, either into the substance of the tissue affected, or upon its surface; there is a tendency to organization, but in both cases its degree may vary,—a perfectly-formed tissue being produced, or a degeneration taking place into pus-globules, according to circumstances (§ 606). Inflammation may result, however, from causes purely local, and primarily affecting the solid tissues; here, therefore, the disturbance of the normal relation is on the other side, yet the production of an increased amount of fibrin is still a character of the disease. Whether the blood moves faster or slower in an inflamed part,—whether the capillaries are contracted or dilated,—are questions, therefore of little moment, in comparison with those which affect the actions of Nutrition and Secretion, to which the fluid, in its passage through the parts in question, ought to be subservient. The same may be remarked of those productions which have been termed *heterologous* transformations of tissue; but which are rather to be regarded as new growths, that have appropriated the nutriment designed for the support of the proper tissues, and have therefore become developed at the expense of these. It is quite as absurd to attempt to account for the growth of Scirrhus, Carcinoma, &c., by any peculiar action of the vessels of the part, as it would be to attribute the secretion of fatty matter by the cells of one tissue, or of phosphate of lime by those of another, to the peculiar distribution of their vessels. The progress of research obviously leads to the conclusion, that in every part of the living body there is an inherent and independent vitality, which enables it to grow and maintain its normal structure and constitution, so long as it is supplied with the requisite materials; and that changes in the character of the tissue can be referred to nothing else than to alterations in its properties, resulting from external agencies, or to alterations in the materials supplied for its renewal. Of these two morbific causes, the latter is undoubtedly the most frequent; and the tendency which is now gaining ground, to seek in the Flood for indications of pathological changes, when there is an obvious general disturbance of the system, will probably lead to a greatly-increased knowledge of the real nature of diseased states; in spite of the opposition which any return to the Humoral Pathology is sure to excite, in the minds of those who regard it as an exploded and pernicious system.

717. The Sympathy between different parts of the system, which especially manifests itself in the tendency to simultaneous affection with the same disease, affords an excellent illustration of this principle. Of those sympathetic actions, which result from the nervous connections of the various organs, this is not the place to speak; since we are at present concerned with those perversions of the nutritive processes, which give rise to inflammatory and other diseases. Where a certain tissue, throughout the body, is similarly affected, there is strong reason to presume that the morbific cause is conveyed to it in the blood; this is the case, for example, with regard to the mucous membranes, which all manifest a tendency to inflammation, when arsenic has been received into the system; and certain forms of the disease commonly termed Influenza are marked by a similar disposition. The same may be said in regard to inflammation of the fibrous membranes, the fibro-cel-

lular tissue, serous membranes, and other structures. It has been considered a sufficient account of these consentaneous affections, to say that they result from sympathy,—a mere verbal quibble, which explains nothing. If, on the other hand, we regard the disease as a perversion of the ordinary processes of nutrition, secretion, &c., and as dependent upon an abnormal condition of the blood (such as is induced by the introduction of a poison into it), the rationale of the sympathetic disturbance becomes apparent,—since all the tissues of the same kind will of necessity be similarly affected, although some local cause may occasion one to suffer more severely than another. In the ingenious paper by Dr. W. Budd already referred to (§ 590), the perfect correspondence which not unfrequently manifests itself between the diseased actions on the two sides of the body, is adduced in support of the same view, to which it is made to afford very striking confirmation. The fact that this kind of sympathy not unfrequently manifests itself between tissues having an analogous structure but very different function, is another argument in favour of the same view; of this fact, the sympathy, of which every practical man is aware, between the skin and mucous membranes, is a very good example. The sympathy of the different tissues forming any individual organ, by which disease in one becomes a cause of disorder in the rest, is, however, to be very differently explained. We have examples of this in inflammatory affections of the mucous membranes, which usually extend themselves to the remaining constituents of the organs of which they form a part; and in those of the serous membranes, which almost always follow inflammation of the organs they invest. Here the local disturbance of one part appears sufficient to account for the extension of it to another that is closely connected with it by vessels and nerves; this has been termed the sympathy of contiguity. The fibrous membranes are less liable to be affected in this manner, than are most other tissues; and the reason appears simply this,—that there is usually less vascular connection between them and the subjacent parts, than there is in the case of the serous membranes. Hence the fibrous membranes frequently act as insulators, preventing the spread of disease to adjacent parts.

718. The general characters of the processes of Nutrition and Secretion are so nearly allied, that what has been stated of the Pathological states of the former, is nearly as applicable to those of the latter. Although it is unquestionable that disordered Secretion may result from a purely local cause, acting on the solid tissue of the part affected, yet there is also increasing reason to believe, that in a large number of cases, the abnormal character of the secretion is in reality a result of the abnormal state of the blood from which it is separated; and that the organ itself is still performing a healthy function, in separating from the blood that which would be injurious to it. This leads us to refer such disorders to causes much more remote than those which were formerly supposed to operate; but they are undoubtedly nearer the true ones. Such a view has been prosecuted by Dr. Prout in regard to the abnormal conditions of the Urine, with great success; and there can be little doubt that it is also applicable to the Biliary secretion, on the true chemical nature of which there is scarcely yet an agreement amongst Chemists, and whose pathological conditions, therefore, are, and must long remain, comparatively obscure. It is obvious that, if the assimilation of nutritive matter be in any respect wrongly performed, the products of the decomposition of the tissues (in which these secretions probably originate, § 648) must also be different; and our remedial measures must often be directed, therefore, not so much to the secreting organ, as towards the previous operations. These hints, which may to some appear of too abstract a character to be of

any practical value, are introduced here, for the purpose of directing the intelligent student in the path that will conduct him to fields of inquiry scarcely yet trodden, and fertile in the most valuable results. In the present unsettled state of opinion upon many of the highest questions in Pathology, it would be absurd to attempt to lay down, in a dogmatic form, what *is;* but much may be done, by purifying the science of what *is not;* and here a sound Physiology affords most valuable assistance.

Animal Heat.

719. All the vital actions that have been considered in the preceding pages, require a certain amount of heat as a condition of their performance; and in the more elevated tribes of animals, in which (for the very purposes of their creation) a high degree of constancy and regularity is required in these actions, there is a provision within themselves for the maintenance of their temperature at a certain standard. We shall inquire, in the first place, into the amount of heat thus generated by Man; and then into the sources of its production.

720. Our present knowledge of the temperature of the Human body under different circumstances, is chiefly due to the investigations of Dr. J. Davy. Much additional information may be expected, however, from inquiries which are at present in progress. Dr. Davy's observations* have included 114 individuals of both sexes, of different ages, and among various races, in different latitudes, and under various temperatures; the external temperature, however, was in no instance very low, and the variations were by no means extreme. The mean of the ages of all the individuals was twenty-seven years. The following is a general statement of the results, the temperature of the body being ascertained by a thermometer placed under the tongue.

Temperature of the air	60°	Average temperature of the body	98·28°
" " "	69°	" " "	98·15°
" " "	78°	" " "	98·85°
" " "	79·5°	" " "	99·21°
" " "	80°	" " "	99·67°
" " "	82°	" " "	99·9°
Mean of all the experiments	74°	Mean of all the experiments	100°
Highest temperature of air	82°	Highest temperature of body	102°
Lowest temperature of air	60°	Lowest temperature of body	96·5°

From this we see that the variations noted by Dr. Davy, which were evidently in part the consequence of variations in temperature, but which were also partly attributable to individual peculiarities, amounted to 5½ degrees; the lower extreme would probably undergo still further depression, if the inquiries were carried on in very cold climates. The temperature of the body may be affected by internal as well as by external causes; thus in diseases which involve an accelerated pulse and an augmented respiration, the temperature is generally higher than usual, even though a large portion of the lung may be unfit for its function. This is often remarkably seen in the last stages of Phthisis, when the inspirations are extremely rapid, and the pulse so quick as scarcely to admit of being counted; the skin, in such cases, often becomes almost painfully hot. On the other hand, in dis-

* Philos. Transact., republished in Anatomical and Physiological Researches.

eases of the contrary character, such as Asthma and the Asiatic Cholera, the temperature of the body falls, sometimes to the extent of 20 degrees. The following observations have been made on this subject by M. Donné;* it is much to be desired, however, that fuller data could be collected on the subject. In a case of puerperal fever, the pulse being 168, and the respirations 48 per minute, the temperature was 104°. In a case of hypertrophy of the heart, the pulse being 150 and the respirations 34, the temperature was 103°. In a case of typhoid fever, the pulse being 136 and the respirations 50, the temperature was 104°. And in a case of phthisis, the pulse being 140 and the respirations 62, the temperature was 102°. On the other hand, in a case of jaundice, in which the pulse was but 52, the temperature was only 96·40°; but the same temperature was observed in a case of diabetes, in which the pulse was 84. The limited results of M. D.'s experiments, whilst they clearly indicate that a *general* relation exists between the temperature of the body and the rapidity of the pulse, also show that this relation is by no means invariable, but that it is liable to be affected by several causes, of which our knowledge is as yet very limited. Dr. Dunglison speaks of having frequently seen the thermometer at 106° in scarlatina and typhus; and Dr. Edwards mentions a case of tetanus, in which it rose to 110¾°.

721. Although there appears to be, for all species of animals, a distinct limit to the variations of bodily temperature, under which their vital operations can be carried on, this limitation does not prevent animals from existing in the midst of great diversities of external conditions; since they have within themselves the power of compensating for these, in a very extraordinary degree. This power seems to exist in Man to a higher amount than in most other animals; since he can not only support but enjoy life under extremes, either of which would be fatal to many. In many parts of the tropical zone, the thermometer rises every day through a large portion of the year to 110°; and in British India it is said to be seen occasionally at 130°. On the other hand, the degree of cold frequently sustained by Arctic voyagers, and quite endurable under proper precautions, appears much more astonishing; by Capt. Parry, the thermometer has been seen as low as —55°, or 87° below the freezing point; by Capt. Franklin at —58°, or 90° below the freezing point; and by Capt. Back at —70°, or 102° below the freezing point. In both cases the effect of the atmospheric temperature on the body is greatly influenced by the condition of the air as to motion or rest; thus, every one has heard of the almost unbearable oppressiveness of the sirocco or hot wind of Sicily and Italy, the actual temperature of which is not higher than has often been experienced without any great discomfort when the air is calm; and, on the other side, it may be mentioned that, in the experience of many Arctic voyagers, a temperature of —50° may be sustained, when the air is perfectly still, with less inconvenience than is caused by air in motion at a temperature fifty degrees higher. This is quite conformable to what might be anticipated on physical principles.

722. Again, the degree of moisture contained in a heated atmosphere makes a great difference in the degree of elevation of temperature which may be sustained. Many instances are on record, of a heat of from 250° to 280° being endured in dry air for a considerable length of time, even by persons unaccustomed to a peculiarly high temperature; and persons whose occupations are such as to require it, can sustain a much higher degree of

* Archives Générales, Oct. 1835; and Brit. and For. Med. Rev. Vol. ii. p. 248.

heat; though not perhaps for any great length of time. The [illegible] the late Sir. F. Chantry have been accustomed to enter a [illegible] his moulds were dried, whilst the floor was red-hot, and a [illegible] the air stood at 350 and Chabert the "Fire-king" was [illegible] ing an oven whose temperature was from 400° to 600°. It is [illegible] these feats might be easily matched by many workmen who [illegible] exposed to high temperatures, such as those employed in [illegible] glass-houses, and gas-works. In all these instances, the [illegible] facilitates the rapidity of the vaporization of the fluid, of which [illegible] occasions the secretion by the cutaneous glands: and the large [illegible] caloric which becomes latent in the process, is for the most part drawn from the body the temperature of which is thus kept [illegible] posure to a very elevated temperature, however, if continued [illegible] length of time, does produce a certain elevation of that of the body, [illegible] be expected from the statements already made in regard to the [illegible] the heat of the body with changes in atmospheric temperature. [illegible] the experiments of MM. Berger and Delaroche, it was found [illegible] body had been exposed to air of 120° during 17 minutes, a [illegible] placed in the mouth rose nearly 6 degrees above the ordinary [illegible] it may be remarked, however, that as the body was immersed [illegible] box, from which the head projected in order to avoid the [illegible] of the heated air on the temperature of the mouth, the air [illegible] become charged with the vapour exhaled from the surface, and [illegible] fore somewhat of the effects of a moist atmosphere. At [illegible] perature of the body does not appear to rise under any [illegible] degree very much greater than this. In one of the experiments [illegible] Fordyce and Blagden, the temperature of a dog that had [illegible] [illegible] 23 [illegible] 101 [illegible] MM [illegible]

[illegible]

possessed by the living system, in the higher animals, of keeping up its temperature to an elevated standard, and of preventing it from being raised much beyond it by any degree of external heat, we have next to inquire to what this faculty is due. We shall be more likely to arrive at accurate results in such an inquiry, the more comprehensive is our survey of the phenomena to which it relates.* The most recent experiments on the temperature of Plants (those made by MM. Becquerel and Breschet with the thermo-multiplier) have demonstrated that in those parts in which the vital processes are taking place with activity, a sensible amount of caloric is being constantly evolved. The amount of this evolution of heat is generally very low,—not more, in fact, than a single degree (Fahr.); and as it does not more than counterbalance the effect of the evaporation, which is continually taking place from the surface, there is no sensible difference between the temperature of the plant and that of the surrounding air. At the time of flowering, however, a much greater degree of heat is generated in many plants; especially in those in which a large number of flowers are crowded together, as is the case in the Arum tribe: thus a thermometer placed in the midst of twelve spadixes has been seen to rise to 121°, whilst the temperature of the air was only 66°. During the germination of seeds, again, a considerabe development of heat takes place; this, which is soon carried off from a single seed, becomes very sensible when a large number are heaped together, as in malting; the thermometer plunged into a heap of germinating barley having been seen to rise to 110°.

724. These facts are of more importance than might appear at first sight; for they indicate unequivocally that the source of the heat is to be looked for in the Organic functions, not in those of Animal life. The evolution of caloric has been attributed by many physiologists to the nervous system; the influence which this system evidently possesses over the function, being mistaken for the efficient cause of it. As has been remarked on several former occasions, however,—the fact that any change takes place in Vegetables to the same degree (under certain conditions) with that in which it ever presents itself in Animals, is a sufficient proof that it cannot be *dependent* upon nervous agency, although it may be influenced by it. Moreover it may be remarked, that the production of heat is an operation of an entirely *physical* character, and that it may be referred to physical causes; whilst the operations in which the nervous system is concerned, are such as we cannot liken in any degree to physical phenomena, and are of a purely *vital* character. In our inquiry into the sources of the heat evolved by living beings, we are limited, therefore, to those which can operate in the Vegetable kingdom; and on examining into the phenomena which present any relation to this, we are at once struck with the fact, that an absorption of oxygen from the air, with an extrication of carbonic acid, is continually taking place (constituting the true respiratory process of Plants, § 522); and that these changes occur with excessive activity, at the very periods at which the evolution of heat is most remarkable,—those, namely, of germination and flowering. The quantity of oxygen consumed by flowers is enormous, —those of the Arum Italicum having been found to convert 40 times their own bulk of that gas into carbonic acid, between the periods of their first appearance and their final decay; and of this, the far larger proportion is consumed by the sexual apparatus, which has been found to consume 132 times its own bulk of oxygen in 24 hours. That this change is a condition

* This subject is more fully treated in the Author's Principles of General and Comparative Physiology, §§ 548—567.

necessary for the production of heat, is fully proved by the fact, that no caloric is evolved when the flowers are excluded from the contact of oxygen; whilst the substitution of pure oxygen for atmospheric air occasions the elevation of temperature to be more rapid and considerable than usual.* The same may be said of the heat liberated by seeds in the act of germination: a large amount of oxygen is absorbed, and of carbonic acid given out, during this process, and the evolution of heat may be easily shown to be as dependent upon this change, as in the instance just quoted. It is the opinion of some physiologists, that the production of heat under these circumstances is dependent upon a real process of combustion; the carbon of the plant uniting with the oxygen of the air, and thereby giving out caloric, as it does in the ordinary burning of charcoal. Perhaps this account is rather too simple. It is well known that most chemical changes, especially those in which there is an alteration in the form of the agents concerned, are attended with a change of temperature; and it is not unreasonable to suppose, that, of those molecular alterations which have been shown to be so continually occuring in the living system, some may be connected with the disengagement of heat peculiar to it. For the continuance of these alterations, however, the absorption of oxygen and the extrication of carbonic acid are necessary conditions; if these be suspended, therefore, the temperature soon falls.

725. When the phenomena of calorification in Animals are carefully examined, they are found to harmonize completely with this view. Throughout the whole kingdom, an exact conformity may be perceived, between the amount of oxygen consumed and of carbonic acid given off, and the degree of heat liberated. In the cold-blooded animals, whose temperature is almost entirely dependent upon that of the surrounding medium, the respiration is feeble, being carried on, for the most part, through the medium of water. In the warm-blooded Vertebrata, however, which have the power of keeping up the heat of their bodies to an elevated standard, even when that of the surrounding air is far beneath it, the quantity of oxygen consumed is very large; and that required by Birds is more, in proportion to their size, than that employed by Mammalia, as we should expect from the more elevated temperature of the former. In the class of Insects, we have a very remarkable illustration of the same general fact. It appears, from the researches of Mr. Newport, that Insects, during their larva and pupa states, and even in their perfect condition when at rest, are to be regarded as truly cold-blooded animals; their temperature rising and falling with that of the surrounding medium, and being at no time more than a degree or two above it. In a state of activity, however, the temperature of the body attains a considerable elevation,—frequently as much as 10° or 15° above that of the air. It must be remembered that, owing to their larger extent of surface in proportion to their bulk, small animals are cooled much more rapidly than large ones; and the temperature of Insects would probably rise much higher, if it were not for the loss they are thus continually experiencing, which is greatly increased by the action of the wings. In one of Mr. N.'s experiments, a single Humble-Bee, in a state of violent excitement, communicated to three cubic inches of air as much as 4° of heat within five minutes, its own temperature being raised 7° in the same time. When several individuals in a state of excitement, however, are clustered together, so that the loss of heat is prevented, the elevation of temperature is much more considerable; thus a thermometer introduced among seven "nursing-bees" stood at 92½°, whilst

* See the very interesting experiments of MM. Vrolik and Vriese, in the Annales Sci. Nat. N. S. Botan. Tom. xi, p. 551.

the external air was only 70°; and the temperature of a hive was raised by disturbing it, during winter, from 48½° to 102°, the temperature of the air being only 34½° at the time! In all these instances, the amount of oxygen consumed bears an exact proportion to that of the heat evolved. Even in higher animals, exercise has a considerable effect in producing an elevation of temperature; and, that this is not merely due to the acceleration of the circulation, is shown by the very curious fact, that the exercise of a particular muscle will cause an increase in the heat liberated from it, as shown by needles plunged in its substance and connected with the thermo-multiplier.* It may, indeed, be stated as a general proposition, applicable as well to different parts of the same being, as to different individuals, that the development of heat is proportional to the activity of the molecular processes which constitute the functions of Nutrition, Secretion, &c.; increasing with their activity, and diminishing with their torpor. It is very easy to explain, on this principle, the known influence of the nervous system on the calorific function; since, although the molecular changes in the organic system are not dependent upon the agency of that system, they are very much influenced by it; and thus we can readily understand how a state of nervous excitement may produce an elevation of temperature, and a depression of nervous power occasion a cooling of the body. The experiments of Sir B. Brodie, Chossat, and others, in which a greater or less portion of the nervous centres was removed, and the animal cooled notwithstanding the maintenance of the circulation, by no means prove that the nervous system is directly concerned in the production of heat; since in all such experiments, there is a gradual loss of those other vital powers, which are concerned in the function of calorification. From the experiments of Dr. W. Philip and Dr. Hastings, it appears that an animal whose nervous centres have been removed, cools much faster when left to itself, than when artificial respiration is practised; and that, if the cooling have made much progress before the artificial respiration is caused to commence, the temperature may be raised;—and this too, in spite of the very imperfect manner in which natural respiration is replaced by movements artificially effected.

726. That the maintenance of Animal Heat is due in part to those molecular changes, to which the extrication of carbonic acid through the skin is subservient, appears from the following experiments recently performed by MM. Becquerel and Breschet. The hair of rabbits was shaved off, and a composition of glue, suet, and resin, forming a coating through which air could not pass, was applied over the whole surface. It might seem natural to suppose that, by preventing the evaporation of the sweat, the temperature of the tissues would be very sensibly increased; and that, by this increase of the temperature of the whole body, a high state of fever would be engendered, with the symptoms of which the animal would at last die. But the contrary occurred. In the first rabbit, which had a temperature of 100° before being shaved and plastered, it had fallen to 89½° by the time the material spread over him was dry. An hour after, the thermometer placed in the same parts (the muscles of the thigh and chest), had descended to 76°. In another rabbit, prepared with more care, by the time that the plaster was dry, the temperature of the body was not more than 5½° above that of the surrounding medium, which was at that time 62½°; and in an hour after this, the animal died. These experiments place in a very striking

* See the experiments of MM. Becquerel and Breschet, in Ann. des Sci. Nat. N. S. Zool., Tom. VI.

point of view the importance of the cutaneous surface as a respiratory organ, even in the higher animals: and they enable us to understand how, when the aerating power of the lungs is nearly destroyed by disease, the heat of the body is kept up to its natural standard by the action of the skin. A valuable therapeutic indication, also, is derivable from the knowledge which we thus gain of the importance of the cutaneous respiration; for it leads us to perceive the desirableness of keeping the skin moist, in those febrile diseases in which there is great heat and dryness of the surface, since aeration cannot properly take place through a dry membrane. Of the relief afforded by cold or tepid sponging in such cases, experience has given ample evidence.

727. It has been, and still is, a prevalent opinion amongst Physiologists of the Chemical school, that the process of calorification is one of ordinary combustion; and that, of the whole amount of food taken in, a large proportion is destined to be immediately *burned*, in order to keep up the temperature of the body. This, however, is not giving a true account of it; since it appears from the experiments of Dulong and Despretz (between which there is a close agreement) that more heat is given off from the bodies of warm-blooded animals, than can be accounted for by the union of the amount of carbon and hydrogen, contained in the carbonic acid and watery vapour exhaled by them in the same time, with their equivalents of oxygen. According to Dulong, the combustion of the carbon alone would not account for more than half of the caloric liberated by carnivorous animals, or for more than seven-tenths of that set free by herbivorous species; and, even when the hydrogen was also taken into account, the amount of heat accounted for was only 3-4ths to 4-5ths of that which is developed in the same space of time. The results obtained by Despretz were very similar, for he found that the heat that would be generated by the union with oxygen of a given amount of carbon and hydrogen, was only from 3-4ths to 9-10ths of that which would be set free by an animal, in the time necessary to exhale from the skin and lungs a corresponding amount of carbonic acid and of watery vapour. Moreover, there is no proof whatever, that the watery vapour exhaled from the lungs is a product of the combustion of hydrogen; it is just as likely to be a secretion from the blood. Hence, it is evident that the chemical doctrine in its present form is insufficient to explain the phenomena of animal calorification; but there can be little doubt that an increased knowledge of the molecular changes which go on within the system, will afford a solution of the difficulty. At present, then, it may be stated as a general fact, that the production of Animal Heat is due to the various changes in chemical composition, that are continually taking place within the system; of which changes, the absorption of oxygen, and the disengagement of carbonic acid, are the two chief external manifestations:—and that the degree of caloric liberated bears a close relation to the activity of these changes, either in regard to the body at large, or to any portion of it.

728. The researches of Dr. Edwards upon Animal Heat have brought to light some very interesting facts, regarding the diversity which exists as to the power of generating heat, in the same species of animal at different ages, and at different periods of the year. It appears to be a general fact that, the younger the animal, the less is its independent calorifying power. The development of the embryo of oviparous animals is entirely dependent upon the amount of external warmth supplied to it; and there are many kinds of Birds, which, at the time they issue from the egg, are so deficient in the power of generating heat, that the temperature rapidly falls, when

they are removed from the nest and placed in a cold atmosphere. It was shown by collateral experiments, that the loss of heat was not to be attributed to the absence of feathers, nor to the extent of surface exposed in comparison with the bulk of the body; and that nothing but an absolute deficiency in the power of generating it, would account for the fall of temperature. This is quite conformable to facts well ascertained in regard to Mammalia. The fœtus, during intra-uterine life, has little power of keeping up its own temperature; and in many cases it is much dependent on external warmth, for some time after birth. The degree of this dependence, however, differs greatly in the various species of Mammalia, as among Birds; being less, in proportion as the general development is advanced. Thus, young Guinea-pigs, which can run about and pick up food for themselves almost as soon as they are born, are from the first independent of parental warmth; whilst, on the other hand, the young of dogs, cats, rabbits, &c., which are born blind, and which do not, for a fortnight or more, acquire the same development with the preceding, rapidly lose their heat when withdrawn from contact with the body of the mother. In the Human species it is well known, that external warmth is necessary for the infant; but the fact is too often neglected (under the erroneous idea of hardening the constitution) during the early years of childhood. It is to be carefully remembered, that the development of Man is slower than that of any other animal; and that his calorifying power is closely connected with his general bodily vigour. In the case of children born very prematurely, the greatest attention must be given to the sustenance of the heat of the body; and though the infant becomes more independent of it as development advances, it is many years before the standard can be maintained without assistance, throughout the ordinary vicissitudes of external temperature. The calorifying power, which is fully possessed by adults, decreases again in advanced age. Old people complain that their "blood is chill;" and they suffer greatly from exposure to cold, the temperature of their whole body being lowered by it.

729. These facts have a very interesting connection with the results of statistical inquiries, as to the average number of deaths at different seasons, recorded by M. Quetelet.*

	First Month.	2–3 Years.	8–12 Years.	25–30 Years.	50–65 Years.	90 Years and above.
January	1·39	1·22	1·08	1·05	1·30	1·58
February	1·28	1·13	1·06	1·04	1·22	1·48
March	1·21	1·30	1·27	1·11	1·11	1·25
April	1·02	1·27	1·34	1·06	1·02	0·96
May	0·93	1·12	1·21	1·02	0·93	0·84
June	0·83	0·94	0·99	1·02	0·85	0·75
July	0·78	0·82	0·88	0·91	0·77	0·64
August	0·79	0·73	0·82	0·96	0·85	0·66
September	0·86	0·76	0·81	0·95	0·89	0·76
October	0·91	0·78	0·76	0·93	0·90	0·74
November	0·93	0·91	0·80	0·97	1·00	1·03
December	1·07	1·01	0·96	0·97	1·15	1·29

We see from this table that, during the first month of infant life, the external

* Essai de Physique Sociale, Tom. I. p. 197.

temperature has a very marked influence; for the average mortality during each of the three summer months being 80, that of January is nearly 140, and the average of February and March is 125. This is exactly the result obtained by MM. Villermé and Milne-Edwards, in their researches on the mortality of the children conveyed to the Foundling Hospitals in the different towns in France; and they not only ascertained that the mortality is much the greatest during the first three months in the year, but also that it varies in different parts of the kingdom, according to the relative severity of the winter. As childhood advances, however, the winter mortality diminishes, whilst that of the spring undergoes an increase; this is probably due to the greater prevalence of certain epidemics at the latter season; for the same condition is observed in a still more remarkable degree between the ages of 8 and 12 years, the time when children are most severely affected by such epidemics. As the constitution acquires greater vigour, and the bodily structure attains its full development, the influence of the season upon mortality becomes less apparent; so that, at the age of from 25 to 30 years, the difference between the summer and winter mortality is very slight. This difference reappears, however, in a very marked degree, at a later period, when the general vigour, and the calorifying power, undergo a gradual diminution. Between the ages of 50 and 65 it is nearly as great as in early infancy; and it gradually becomes more striking, until, at the age of 90 and upwards, the deaths in January are 158 for every 64 in July (a proportion of $2\frac{1}{2}$ to 1); and the average of the three winter months is 145, whilst that of the three summer months is only 68, or less than one-half.

730. Not only does the same individual possess different degrees of calorifying power at different periods of his life, but also at different parts of the year. Dr. Edwards found that Sparrows, when exposed for some time to a temperature of 32° during the summer, rapidly lost heat, the refrigeration during 3 hours being from 6 to 21 degrees; but that, when they were placed in the same circumstances during the winter (after having been accustomed to a warm temperature), the refrigeration was much less, not being in any instance more than 2° in 3 hours. Although it would be difficult to prove the fact experimentally in regard to Man, there can be little doubt that he shares with the other Mammalia in this variation. It is well known that the general vigour of the system is less in summer than in winter,—in hot climates than in moderately cold; and that the digestive powers are especially weakened. Moreover, we continually experience the great discomforts of a cold day in summer; when, our system not being prepared for it, we can less readily maintain our temperature at its normal standard. The practical inference,—that we should be much on our guard against exposure to low temperatures during summer,—is one of much importance, and its value has been fully confirmed by experience. The same principle may also be applied to the explanation of the well-known fact, that those who have been long resident in warm climates feel the cold acutely; whilst those who have been inured to cold are able to resist it much better than those who are exposed to it for the first time. The former have a continued *summer* constitution; and their system, not being called upon by its external conditions to produce much heat, the power is after a time partially lost. On the other hand, those who live in cold climates have a perpetual *winter* constitution (as it were) established; and the amount of heat generated by them is much greater. It will be obvious that this must be the case, if Man's capability of living under the greatest varieties of climate be sufficiently considered. From Dr. E.'s experience it appears, that every

month makes an evident difference in the seasonal degree; the heat lost by sparrows in August being much less than that lost by birds of the same species in July.

731. Having thus considered the means by which the degree of heat necessary for the performance of the functions of the Human system is generated, we have to inquire how its temperature is prevented from being raised too high; in other words, what frigorifying means there are, to counterbalance the influence of causes, which in excess would otherwise be fatal, by raising the heat of the body to an undue degree. How is it, for example, that when a person enters a room whose atmosphere is heated to one or two hundred degrees above his body, the latter does not partake of the elevation, even though exposed to the heat for some time? Or, since the inhabitants of a climate where the thermometer averages 100° for many weeks together, are continually generating additional heat in their own bodies, how is it that this does not accumulate, and raise them to an undue elevation? The means provided by Nature for cooling the body when necessary, are of the simplest possible character. From the whole of its soft moist surface, simple evaporation will take place at all times, as from an inorganic body in the same circumstances; and the amount of this will be regulated merely by the condition of the atmosphere as to warmth and dryness. The more readily watery vapour can be dissolved in atmospheric air, the more will be lost from the surface of the body in this manner. In cold weather, very little is thus carried off, even though the air be dry; and a warm atmosphere, already charged with dampness, will be nearly as ineffectual. But simple evaporation is not the chief means by which the temperature of the body is regulated. The Skin, as already mentioned (§ 701), contains a large number of glandulæ, the office of which is to secrete an aqueous fluid; and the amount of this secretion appears to depend solely or chiefly upon the *temperature* of the surrounding air. Thus, when the external heat is very great, a considerable amount of fluid is transuded from the skin; and this, in evaporating, converts into latent heat a large quantity of the free caloric, which would otherwise raise the temperature of the body. If the atmosphere be hot and dry, and also be in motion, both transudation and evaporation go on with great rapidity. If it be cold, both are checked,—transudation almost entirely so; but if it be dry some evaporation still continues. On the other hand, in a hot atmosphere saturated with moisture, transudation continues, though evaporation is almost entirely checked; and the fluid poured out by the exhalent glands accumulates on the skin. There is reason to believe that the secretion continues, even when the body is immersed in water, provided its temperature be high. We learn from these facts the great importance of not suddenly checking transudation, by exposure of the surface to cold, when the secretion is being actively performed; since a great disturbance of the circulation will be likely to ensue, similar to that which has been already mentioned, as occurring when other important secretions are suddenly suspended.

CHAPTER XIV.

OF REPRODUCTION.

732. The Function of Reproduction has been commonly regarded as so entirely different in character from the ordinary nutritive processes, that no analogy can be drawn between them. The results of late inquiries, however, leave no doubt that the difference between them is extremely small,—having, in fact, a relation rather to the *object* of the action, than to the mode in which it is performed. In the ordinary function of Nutrition, there is a continual regeneration or reproduction of the tissues and organs of the body; but the new parts are destined still to constitute the same *whole*. On the other hand, in Reproduction, the newly-formed parts are destined from the first to be cast off from the parent structure, and to become new individuals. Still, their origin is essentially the same in both instances, as appears from the mode in which the multiplication of the lower plants and animals takes place. Thus in the simplest Cryptogamia, such as the Yeast Fungus,* every single cell may be regarded as a distinct individual, since it is capable of living by itself, and of generating new cells; and thus the production of a new cell, in connection with the original one, may be regarded as alike an act of Nutrition and of Reproduction. So again in the Hydra and other Polypes, the remarkable power of reparation which is manifested in their Nutritive operations may be employed in generating new individuals; since, when the body is divided into numerous parts, each one of these has the power of developing all the rest of the structure, and thus of becoming a complete animal (§ 21). Still we find in most Plants, and in all Animals, some portion of the structure specially designed to form and to set free germs, which are destined to become new individuals; and it is in the liberation and development of these, that the function of Reproduction essentially consists. In Plants it is very evident that these germs differ but little from those which elsewhere produce new cells (§ 557); and that the first aspect of the new being is neither more nor less than a single cell, in which all the other cells of the structure subsequently originate. In the Cryptogamia, the cell-germs are contained in what is termed the *spore;* and, when liberated from the parent, they are developed into cells without any further assistance, than that which they derive from the air, moisture, &c. that surround them. In Flowering Plants, on the other hand, the cell-germs are conveyed into a new set of organs, in which they are supplied with nutriment previously elaborated for them by the parent; and, in this manner, they are enabled to attain an ultimate development, which is much higher than that of the Cryptogamia. It is now well established, that the pollen-grain of Phanerogamia is analogous to the spore of Cryptogamia; since it contains the reproductive granules, which are the germs of the first cells of the new individual. When the pollen-grains are cast upon the stigmatic surface, they project one or more long tubes, which insinuate themselves down the soft loose tissue of the style, and reach the ovarium. Into these tubes, the granules which the pollen grain contained are seen to pass; and they are thus conveyed into the ovules, the foramina of which are penetrated by the extremities of the pollen-tubes. The ovules previously contained nothing but starchy matter; but from the time that the pollen-tubes have thus implanted (as it were) their contents in their cavity,

* See Principles of General and Comparative Physiology, § 98.

they may be considered as fecundated. The subsequent growth of the embryo from the first-formed cells, takes place according to the principles already stated, under the head of Nutrition; and thus it is seen, that the mysterious process of Reproduction evidently consists, in Flowering Plants, of nothing else than the implantation of a cell-germ prepared by the *male* organs, in a nidus or receptacle adapted to aid its early development, which nidus constitutes the essential part of the female system.

733. There is now good reason to believe that, in no Animals, is the Reproductive apparatus less simple than it is in the higher Plants;—that is to say, in every instance, two sets of organs, a *germ-preparing* and a *germ-nourishing*, are present. These organs differ much in form and complexity of structure, in the various tribes of Animals; but their essential function is the same in all. Those which are termed Male organs prepare and set free certain bodies, which, having an inherent power of motion, have been supposed to be independent Animalcules, and have been termed Spermatozoa; there is but little reason, however, to regard them in this light, since ciliated epithelium-cells, and even the blood corpuscles (under peculiar circumstances, (§ 747), may exhibit as much activity; and there is no evidence that their function is any higher than that of the pollen-tube of Plants, which conveys into the ovulum the germs of the first cells of the embryo. This view of the character of the Spermatozoa, which is perfectly consonant with the nature of their movements and with the mode of their production,* derives confirmation from Dr. Barry's recent statements regarding their ultimate origin,† which he shows to be the same as that of the animal tissues in general. His previous observations on the history of the Ovum, and on the nature of the act of fecundation (which will be presently given in some detail) left scarcely any doubt that this act consisted in the introduction of some new element into the ovule, through the medium of the Spermatozoa, the arrival of which at the surface of the ovary had been more than once seen, and the penetration of which to the ovum there was good reason to suspect. All doubt has been lately removed by the observations of Dr. A. Farre on the ovum of the Earth-worm, which he has distinctly seen to be penetrated by Spermatozoa; and the act of fecundation is evidently analogous, therefore, in Animals, to the process which has been described as taking place in the Flowering Plants. {Dr. Martin Barry has twice observed Spermatozoa within the mammiferous ovum. The ova were those of a rabbit, taken from the Fallopian tube within twenty-four hours *post coitum*. The spermatozoa were within the thick transparent membrane, (zona pellucida,) brought with the ovum from the ovary.—M. C.} In many of the lower tribes of Animals, the spermatic fluid effused by an individual of one sex comes into direct contact with the ova previously deposited by the other; but in all the higher tribes, as in Man, the act of fecundation is performed before the ova have quitted the ovarium. With these general views, we shall now be prepared to consider the share which each sex has in the Function of Reproduction.

Function of the Male.

734. The Spermatic fluid secreted by the Testes of the Male (§ 700), differs from all other secretions, in containing a large number of very minute bodies, only discernible with a high power of the Microscope; and these,

* See Principles of General and Comparative Physiology, § 607.
† Philosophical Transactions, 1841, Part II.

in ordinary cases, remain in active motion for some time after they have quitted the living body. The Human Spermatozoon, of which representations are given in the Frontispiece (Fig. 18), consists of a little oval flattened body from the 1-600th to the 1-800th of a line in length, from which proceeds a long filiform tail, gradually tapering to the finest point, of 1-50th or at most 1-40th of a line in length. The whole is perfectly transparent; and nothing that can be termed structure can be satisfactorily distinguished within it. The movements are principally executed by the tail, which has a kind of vibratile undulating motion. They may continue for many hours after the emission of the fluid; and they are not checked by its admixture with other seminal secretions, such as the urine and the prostatic fluid. Thus, in cases of nocturnal emission, the Spermatozoa may not unfrequently be found actively moving through the urine in the morning; and those contained in the seminal fluid collected from females that have just copulated, are frequently found to live many days. Their presence may be readily detected by a Microscope of sufficient power, even when they have long ceased to move, and are broken into fragments; and the Physician and the Medical Jurist will frequently derive much assistance from an examination of this kind. Thus, cases are of no uncommon occurrence, especially among those who have been too much addicted to sexual indulgence, in which seminal emissions take place unconsciously and frequently, and produce great general derangement of the health; and the true nature of the complaint is obscure until the fact has been detected by ocular examination. Again, in charges of rape, in which evidence of actual emission is required, a microscopic examination of the stiffened spots left on the linen will seldom fail in obtaining proof, if the act have been completed: in such cases, however, we must not expect to meet with more than fragments of Spermatozoa; but these are so unlike any thing else, that little doubt need be entertained regarding them. It has been proposed to employ the same test in juridical inquiries respecting doubtful cases of death by suspension; seminal emissions being not unfrequent results of this kind of violence: but there are many obvious objections which should prevent much confidence being placed in it.*

735. The mode of evolution of Spermatozoa, which has been recently discovered by Wagner, is so different from the ordinary method of production amongst Animalcules, as of itself to indicate that the former cannot be referred to the same category with the latter. It may be best studied in those animals which have only a periodical fertility; and the Passerine Birds are among the most convenient subjects for this purpose. During the winter, the testes are small and almost bloodless, and no trace of Spermatozoa can be detected within them; on the return of spring, however, they undergo great enlargement and become almost gorged with blood, and the gradual steps of the evolution of the Spermatozoa may be easily observed. The fluid drawn from them is first seen to contain a number of granular corpuscles, resembling those known as the seminal granules in the human semen (delineated at *a*, Fig. 18, Front.); and in a short time there are seen, in addition to these, numerous rounded transparent vesicles, at first having but one nucleus, and afterwards presenting several. These nuclei bear a close resemblance to the granular corpuscles just mentioned; and it is probable that the former are to be regarded as cytoblasts, from which the transparent vesicles (shown, as existing in the human semen, in Fig. 19, Front.) are

* See the Author's Article "Asphyxia," in the Library of Practical Medicine, and the authorities there referred to.

evolved. The nuclei seem afterwards to resolve themselves into a fine granular matter, which is diffused through the whole vesicle or "cyst of evolution;" and in this a linear arrangement soon becomes perceptible. The lines become more and more distinct, and are at last seen to be evidently produced by the arrangement of the Spermatozoa, which lie side by side within the vesicle; and the form of this changes from a sphere to a long oval. After a time they break forth, but still adhere to each other for a short period, forming bundles, such as may often be met with in the human semen, when taken directly from the testis (Front. Fig. 20).* That the Spermatozoa are the essential elements of the spermatic fluid, has been reasonably inferred from several circumstances, such as their absence or imperfect development in hybrid animals, which are nearly or entirely sterile; and the fact that fecundation essentially consists in the direct communication of one of them with a certain point in the ovum, appears too well established to admit of further doubt. Regarding the uses of the other constituents of the semen, no sufficient account can be given.

736. The power of procreation does not usually exist in the male, until the age of from 14 to 16 years; and it may be considered probable that no Spermatozoa are produced until that period, although a fluid is secreted by the testes. At this epoch, which is ordinarily designated as that of puberty, a considerable change takes place in the bodily constitution: the sexual organs undergo a much-increased development; various parts of the surface, especially the chin and the pubes, become covered with hair; the larynx enlarges, and the voice becomes lower in pitch, as well as rougher and more powerful; and new feelings and desires are awakened in the mind. Instances, however, are by no means rare, in which these changes take place at a much earlier period, the full development of the generative organs, with manifestations of the sexual passion, having been observed in children of but a few years old. The procreative power may last, if not abused, during a very prolonged period. Undoubted instances of virility at the age of more than 100 years are on record; but in these cases, the general bodily vigour was preserved in a very remarkable degree. The ordinary rule seems to be, that sexual power is not retained by the male in any considerable degree, after the age of 60 or 65 years. To the use of the sexual organs for the continuance of his race, Man is prompted by a powerful instinctive desire, which he shares with the lower animals. This instinct, like the others formerly alluded to (§§ 259—63), is excited by sensations; and these may either originate in the sexual organs themselves, or may be excited through the organs of special sensation. Thus in Man it is most powerfully aroused by impressions conveyed through the sight or the touch; in many other animals, the auditory and olfactive organs communicate impressions which have an equal power; and it is not improbable that, in certain morbidly-excited states of feeling, the same may be the case in ourselves. That local impressions have also a very powerful effect in exciting sexual desire, must have been within the experience of almost every one; the fact is most remarkable, however, in cases of satyriasis, which disease is generally found to be connected with some obvious cause of irritation of the generative system, such as pruritus, active congestion, &c. That some part of the Encephalon is the seat of this as of other instinctive propensities, appears from the considerations formerly adduced (Chap. III.); but that the Cerebellum is the part in which this function is

* For a fuller account, with illustrations, of the development of the Spermatozoa, and its analogy with the formation of other tissues, see Princ. of Gen. and Comp. Phys. §§ 430 and 607.

specially located, cannot be regarded as by any means sufficiently proved (§§ 274—8). The instinct, when once aroused (even though very obscurely felt), acts upon the mental faculties and moral feelings; and thus becomes the source, though almost unconsciously so to the individual, of the tendency to form that kind of attachment towards one of the opposite sex, which is known as *love*. This tendency cannot be regarded as a simple passion or emotion, since it is the result of the combined operations of the reason, the imagination, and the moral feelings; and it is in the engraftment (so to speak) of the psychical attachment, upon the mere corporeal instinct, that a difference exists between the sexual relations of Man and those of the lower animals. In proportion as the human being makes the temporary gratification of the mere sexual appetite his chief object, and overlooks the happiness arising from spiritual communion, which is not only purer but more permanent, and of which a renewal may be anticipated in another world,—does he degrade himself to the level of the brutes that perish. Yet how lamentably frequent is this degradation!

738. When, impelled by sexual excitement, the male seeks intercourse with the female, the erectile tissue of the genital organs becomes turgid with blood (§ 519), and the surface acquires a much-increased sensibility; this is especially acute in the glans penis. By the friction of the glans against the rugous walls of the vagina, the excitement is increased; and the impression which is thus produced at last becomes so strong, that it produces, through the medium of the spinal cord, a reflex contraction of the muscles which surround the vesiculæ seminales (§ 203). These receptacles discharge their contents (partly consisting of semen, and partly of a secretion of their own) into the urethra, and from this they are expelled with some degree of force, and with a kind of convulsive action, by its own compressor muscles. Now although the sensations concerned in this act are ordinarily most acutely pleasurable, there appears sufficient evidence that they are by no means essential to its performance; and that the impression which is conveyed to the Spinal Cord *need not* give rise to a sensation, in order to produce the reflex contraction of the ejaculator muscles (§182). The high degree of nervous excitement which the act of coition involves, produces a subsequent depression of corresponding amount; and the too frequent repetition of it is productive of consequences very injurious to the general health. This is still more the case with the solitary indulgence, which (it is to be feared) is practised by too many youths; for this, substituting an unnatural degree of one kind of excitement for that which is wanting in another, cannot but be still more trying to the bodily powers. The secretion of seminal fluid being, like other secretions, very much under the control of the nervous system, will be increased by the continual direction of the mind towards objects which awaken the sexual propensity (§ 426, *note*); and thus, if intercourse be very frequent, a much larger quantity will altogether be produced, although the amount emitted at each period will be less. The formation of the secretion seems of itself to be a much greater tax upon the corporeal powers, than might have been supposed *à priori;* and it is a well-known fact, that the highest degree of bodily vigour is inconsistent with a frequent indulgence in sexual intercourse; whilst nothing is more certain to reduce the powers, both of body and mind, than excess in this respect. These principles, which are of great importance in the regulations of the health, are but results of the general law, which prevails equally in the Vegetable and Animal kingdoms, that the development of the individual and the reprodction of the species stand in an inverse ratio to each other.

Action of the Female.

739. The most essential part of the female generative system is that in which the ova are prepared; the other organs are merely accessory, and are not to be found in a large proportion of the Animal kingdom. In many of the lower animals, the ovaria and testes are so extremely like each other, that the difference between them can scarcely be distinguished; and the same has already been stated regarding the condition of these organs in Man, at an early period of development. The fact is one of no small interest. In the lower animals, the ovarium consists of a loose tissue containing many cells, in which the ova are formed, and from which they escape by the rupture of the cell-walls; in the higher animals, as in the Human female, the tissue of the ovarium is more compact, forming what is known as the ***stroma;*** and the ova, except when they are approaching maturity, can only be distinguished in the interstices of this, by the aid of a high magnifying power. We owe to Dr. Barry the discovery of the earliest stages in the production of the ovum and its accessory parts, in Mammalia and other Vertebrata. In order to understand his account, however, it will be necessary that the parts of which the ovum consists should be first understood. Taking the Fowl's egg as a familiar illustration, it must be remarked, in the first place, that neither the albumen which forms the *white*, nor the shell-membrane with its testaceous covering, exist in the ovarian ovum; these portions being added during its passage along the oviduct. The parts which we have to analyze, are the yelk-membrane and its contents. Within the yelk-membrane, we find, in the first place, the yelk itself; a substance consisting in part of albuminous granules, and in part of oily globules. Towards the centre, the character of the yelk in some degree changes, its colour being lighter, and the granules presenting more the appearance of cells, with minuter globules in their interior. This central portion is termed the ***discus vitellinus.*** Occupying the centre of the yelk (in the immature ovulum) is a large cell, very distinct in aspect from the rest, and having a well-marked nucleus upon its walls. This is termed the ***germinal vesicle;*** and the nucleus, the ***germinal spot.*** The Mammalian ovum contains exactly the same parts, but the yelk is much smaller in proportion, and corresponds in character rather with the discus vitellinus than with the whole yelk of the Bird's egg. The ovum in all Vertebrated animals is produced within a capsule or bag, the exterior of which is in contact with the stroma of the ovarium; this has been termed, in Mammalia, the Graafian vesicle, after the name of its first discoverer; but the more general and appropriate designation of ***ovisac*** has been given to it by Dr. Barry, who has shown that it exists in other classes of Vertebrata. Between the ovum and the ovisac, in Oviparous animals, there is scarcely any interval; but in the Mammalia a large amount of granular matter is present; and this arranges itself into some peculiar structures discovered by Dr. Barry, and presently to be described. The membrane which surrounds the yelk in Mammalia has received, on account of its thickness and peculiar transparency, the designation of ***zona pellucida.*** The several parts of the ovum now described are shown in Fig. 5 of the Frontispiece.

740. From the researches of Dr. Barry on the early development of the ovum, it appears that the germinal vesicle is the part which can first be distinctly traced. In Fig. 1 (Front.) is seen a representation of one of its incipient stages, in the Rabbit; there is nothing here visible but a collection of very transparent vesicles, surrounded by a mass of dark granules. In the succeeding stage, represented in Fig. 1, some of the vesicles have enlarged, and the granules immediately surrounding them have become developed into

cells. A more advanced condition is represented (on a smaller scale) in Fig. 3; in which a distinct spot (*b*) is seen on the central vesicle (*a*), marking it as the germinal vesicle; whilst many of the granules surrounding it have become cells, and have taken on a very regular arrangement. After a time, a membrane forms around each cluster of granules, separating it from the stroma of the ovarium; this is the ovisac. At a later period, a separation takes place between the inner and outer portions of the mass of granular matter included between the ovisac and the germinal vesicle; and the separation is completed by the development of a membrane, which envelopes the inner stratum. This stratum becomes the yelk, and includes the most of the oil-particles which previously existed within the ovisac; whilst the portion of the granular mass, exterior to this, gives origin in Mammalia to certain structures of a very peculiar character, which seem to be concerned in the liberation of the ovum from the Graafian vesicle or ovisac. The appearance of the Human ovisac and its contents is seen in Fig. 4 (Front.). The granules immediately surrounding the ovum assume the appearance of cells; and these unite to form a sort of membrane, to which the name of *tunica granulosa* has been given. This is seen at *t g* (Fig. 7). The granules lining the ovisac also combine themselves into a membranous structure, to which Dr. Barry has given the designation of *membrana granulosa* (*gg*, Fig. 6). These are connected by four band-like extensions of the same cellulo-membranous structure, which seem to suspend the ovum in its place; and these are called *retinacula* (*r r*, Figs. 6 and 7). The space between the tunica granulosa and the membrana granulosa, which is not occupied by the retinacula, is filled with fluid, in which few or no cells can be seen. The uses of this structure, so far as they are apparent, will be described when the processes by which the ovum escapes from the ovary are detailed. The ovisac does not form the entire structure which has been described as the Graafian vesicle; for this consists of two layers, of which the inner one is the true ovisac, whilst the outer results from a thickening and condensation of the surrounding layer of the stroma of the ovarium. It is the outer layer only which is vascular; the inner presents no trace of structure; and the increase of the ovum must take place by simple imbibition, through it, of the supply of nutritive matter brought into contact with its exterior.

741. The ovarium may be seen, even in the fœtal animal, to contain immature ova, in which the several parts can be clearly distinguished. At a later period, however, the number of ova greatly increases; and the development of some advances, whilst others degenerate. At the period of puberty, the stroma of the ovarium is crowded with ovisacs, which are still so minute, that in the Ox (according to Dr. Barry's computation) a cubic inch would contain 200 millions of them. The greatest advance is seen in those which are situated nearest the surface of the ovarium; and in these, the Graafian vesicle, with its two coats, may be distinctly traced. It is curious that the outer wall (which is itself a part of the condensed stroma of the ovarium) should contain an immense number of minute ovisacs; so that this, in the adult animal, is the most convenient situation in which to view them: these ovisacs have been termed by Dr. Barry parasitic ovisacs. In those animals whose aptitude for conception is periodical, the development of the ova, to such a degree that they become prepared for fecundation, is periodical also. This development becomes evident, when the parts are examined in an animal which is "in heat," by the projection of the Graafian vesicles from the surface; and it consists not merely in an increase of size, but in certain internal changes presently to be described. In the Human female, the period of puberty, or of commencing aptitude for procreation, is

usually between the 13th and the 16th year; it is earlier in warm climates than in cold,* and in densely-populated manufacturing towns than in thinly-peopled agricultural districts. The mental and bodily habits of the individual have also a considerable influence upon the time of its occurrence; girls brought up in the midst of luxury or sensual indulgence, undergoing this change earlier than those reared in hardihood and self-denial. The changes in which puberty consists are for the most part connected with the reproductive system. The external and internal organs of generation undergo a considerable increase of size; the mammary glands enlarge; and a deposition of fat takes place in the mammæ and on the pubes, as well as over the whole surface of the body, giving to the person that roundness and fulness which is so attractive to the opposite sex, at the period of commencing womanhood.

742. The first appearance of the catamenia usually occurs whilst these changes are in progress, and is a decided indication of the arrival of the period of puberty; but it is not unfrequently delayed much longer; and its absence is by no means to be regarded as a proof of the want of aptitude for procreation, since many women have borne large families, without having ever menstruated. The catamenial discharge appears normally to consist of blood deprived of its fibrin; the fluid being composed of serum, in which red corpuscles are suspended, and being readily distinguishable from true blood by its want of power to clot. When clots are found in it, therefore, a morbid condition of the secreting surface must be inferred. The interval which usually elapses between the successive appearances of the secretion, is about four weeks; and the duration of the flow is from three

* {It has been stated, by almost all physiological writers, that women reach maturity, and that menstruation commences much earlier in hot climates, particularly between the tropics, than in temperate and very cold countries. Haller states that in the warm regions of Asia, the catamenia appear from the 8th to the 10th year; and in Switzerland, Britain, and other temperate regions, at the age of 12 or 13, and later the farther we ascend towards the north. The same view has been held by nearly all subsequent writers on the subject, and they infer that animals, like plants, reach maturity sooner in hot than in cold climates. Dewees says that menstruation occurs later in our northern than in our southern states. From many elaborate and interesting papers which have been published within a few years, especially from those of Mr. Roberton of Manchester, it would seem that the natural period of puberty in women, occurs in a much more extended range of ages, and is much more equally distributed through that range, than others have alleged, and that, in other countries the parallel between plants and fruits does not hold good.

At Gottingen, Osiander ascertained the ages at which 137 women began to menstruate. In 21 of these the catamenia appeared at 14; in 32 at 15; in 24 at 16; 9 at 12; and 1 not before the 24th year. The Indian girls in Canada, and in our north-western states and territories, begin to menstruate frequently at 12, 13 and 14. From the statement of Baron Humboldt, the same is equally true of the Korriacs, and the tribes of northern Asia, where girls of 10 years are sometimes found mothers. The notion that women in Lapland do not menstruate till 20, and then only during summer, is founded on a mistake in Linnæus's Flora Lapponica. Tooke states that the Sclavonian, or native Russians reach puberty at an early age; and Dr. Robert Lee, who was in the Crimea, and all the Russian provinces along the Black Sea, and in the Ukraine, and whose opportunities of observation were extensive, says that his conviction is, that over the whole south of Russia the period of puberty is the same as in Great Britain; and that women cease to bear children at the same age. The same would appear to hold good in Java, and in all the islands of the Indian Archipelago, and in Sierra Leone; and the difference said to exist in Arabia in this respect is due to the early marriages, and universal licentiousness and depravity of morals in that country. It would appear from observations made in the West India Islands, that menstruation occurs there about the same period, and that the alleged difference in this respect between the negress and the white female does not exist.—M. C.}

to six days.* There is, however, great variety in this respect among the inhabitants of different climates, and among individuals; in general, the appearance is more frequent, and the duration of the flow greater, among the residents in warm countries, and among individuals of luxurious habits and relaxed frame, than among the inhabitants of colder climates, or among individuals inured to bodily exertion. The first appearance of the discharge is usually preceded and accompanied by considerable general disturbance of the system; especially pain in the loins and a sense of fatigue in the lower extremities; and its periodical return is usually attended with the same symptoms, which are more or less severe in different individuals. Much discussion has taken place respecting the causes and purposes of the menstrual flow; but no satisfactory conclusion has been attained. The most probable view seems to be that, which regards it as analogous to the heat of the lower animals; many of these having a sero-sanguinolent discharge at that period. There is good reason to believe that in women the sexual feeling becomes stronger at that epoch; and it is quite certain that there is a greater aptitude for conception immediately before and after menstruation, than there is at any intermediate period. {Dr. Raciborski states, that of fifteen women who specified accurately the period of their last menstruation, as well as that of their last coitus, conception took place in five from two to four days previously to the period at which the catamenia were due. In seven, conception dated from coitus, occurring two or three days after menstruation; in two, it took place at the actual period of the catamenia; and in one only as long as ten days after the menstrual period.—M. C.} It is the opinion of Dr. R. Lee, founded on numerous observations, that at each menstrual period there is not only a preparation of ova for fecundation, but actually a rupture of one or more Graafian vesicles, and an escape of the ova into the Fallopian tube or oviduct, just as if fecundation had taken place. It is well known that, among many of the lower animals, the ova are entirely extruded by the female, before the spermatic fluid of the male reaches them, and that even in Birds, this occasionally takes place. There is nothing but what is quite conformable to analogy, therefore, in this view; and it has been confirmed by the independent observations of M. Gendrin {and Dr. Negrier, of Angers}. If it be correct, we must suppose that the ova which thus escape without fecundation speedily degenerate; and in this there is nothing improbable. But from Dr. Barry's observations it seems more likely, that this degeneration usually occurs without the ovum quitting the ovary; this being observed in the Rabbit, as to many ova that are prepared for fecundation, but have not been fertilized by a coitus that has proved successful in several others. The duration of the period of aptitude for procreation, as marked by the persistence of the catamena, is more limited in women than in men, usually terminating at about the 45th year; it is sometimes prolonged, however, for ten or even fifteen years longer; but cases are rare in which women above 50 years of age have borne children. There is usually no menstrual flow during pregnancy and lactation; in fact, the cessation of the catamenia is generally one of the first signs indicating that conception has taken place. But it is by no means uncommon for them to appear once or twice subsequently to conception; and in some women, there is a regular monthly discharge, though probably not of the usual secretion, through the whole

* {It would appear, from the statistical researches of M. Brierre de Boismont, that the two periods at which the largest number of females menstruate, are the 8th and 3d days. A woman who menstruates eight days for thirty years, (the usual period of uterine life,) will consume eight years in this function.—M. C.}

period. Some very anomalous cases are recorded, in which the catamenia never appeared at any other time than during pregnancy, and were then regular. The absence of the catamenia during lactation is by no means constant, especially if the period be prolonged; when the menstrual discharge recurs, it may be considered as indicating an aptitude for conception; and it is well known that, although pregnancy seldom recurs during the continuance of lactation, the rule is by no means invariable.

743. The function of the female, during the coitus, is entirely of a passive character. When the sexual feeling is strongly excited, there is a considerable degree of turgescence in the erectile tissue surrounding the vagina, and composing the greater part of the nymphæ and the clitoris; and there is also an increased secretion from the mucous follicles.* But these changes are by no means necessary for effectual coition; since it is a fact well established, that fruitful intercourse may take place, when the female is in a state of narcotism, of somnambulism, or even of profound ordinary sleep. It has been supposed by some that the os uteri dilates, by a kind of reflex action, to receive the semen; but of this there is no evidence. The introduction of a small quantity of the fluid just within the vagina, appears to be all that is absolutely necessary for conception; for there are many cases on record, in which pregnancy has occurred, in spite of the closure of the entrance to the vagina by a strong membrane, in which but a very small aperture existed. That the Spermatozoa make their way to the ovarium and there fecundate the ovum, appears to be the general rule in regard to the Mammalia; and the question naturally arises,—by what means do they arrive there. It has been supposed that the action of the cilia which line the Fallopian tubes might account for their transit; but the direction of this is from the ovaria towards the uterus, and would therefore be opposed to it. A peristaltic action of the Fallopian tubes themselves may generally be noticed in animals

* {The glands of Duverney have been lately (1840) very accurately described by Professor Tiedemann, his attention having been directed to these organs by the late Dr. Fricke of Hamburg. These glands are situated at either side of the entrance of the vagina, beneath the integument covering the inferior part of the vagina, as well as the superficial perineal fascia, and the constrictor vaginæ muscle. The space they occupy lies between the lower end of the vagina, the ascending ramus of the ischium, the crus clitoridis, and the erector clitoridis muscle. Superiorly are the fibres of the levator ani which are attached to the ischium, and behind these are the transversi-perinei muscles. They are surrounded by very loose cellular tissue. They are rounded, but somewhat elongated, being flat and bean shaped. Their long diameter is from 5 to 10 lines; their transverse diameter 2½ to 4½ lines, and they are from 2¼ to 3 lines thick. The excretory duct is at the anterior edge of the superior part of the gland, and runs beneath the constrictor vaginæ, horizontally forwards and inwards, to the inner face of the nympha, opening in front of the carunculæ myrtiformes, in the midst of a number of small mucous follicles. These glands were first discovered by Duverney in the cow, about the middle of the seventeenth century. Bartholinus subsequently found them in the human female, and his observations were confirmed by Duverney, Morgagni, Santorini, Peyer, &c. Haller denied their existence; and such structure seems to have been forgotten until they were again described by Mr. Taylor (Dublin Journal, Vol. xiii. 1838). They are analogous to Cowper's glands in the male according to Tiedemann, and like them are sometimes wanting, and differ in size. In advanced age they are said to diminish in size, and even disappear. They are present in the females of all animals, where Cowper's glands exist in the males. They secrete a thick, tenacious, grayish-white fluid, which is emitted in large quantities, at the termination of the sexual act, most likely from the spasmodic contraction of the constrictor vaginæ muscle, under which they lie. Its admixture with the male semen is supposed to probably have some connection with impregnation, and it has been suggested that it may be the vehicle of the fecundating principle of the semen. These glands were probably known to the ancients, and it is doubtless their secretion which Hippocrates and others describe as the female semen.—M. C.}

killed soon after sexual intercourse; and in those which have a two-horned membranous uterus, such as is evidently but a dilatation of the Fallopian tube, this partakes of the same movement, as may be well seen in the Rabbit. It is difficult to see, however, in what manner this could propel a quantity of fluid so small as merely to cover the lining of the cavity; and in animals which have a single uterus with thicker walls (as in the Human female), it must evidently be unavailable. Among the tribes whose ova are fertilized out of the body, the power of movement inherent in the Spermatozoa is obviously the means by which they are brought in contact with the ova; and it does not seem unreasonable to suppose, that the same is the case in regard to the higher classes, and that the transit of these curious particles from the vagina to the ovaries, is effected by the same kind of action as that which causes them to traverse the field of the microscope. We shall now consider the changes in the ovum and its appendages, by which it is prepared for fecundation.

744. Up to the period when the ovum is nearly brought to maturity, it remains in the centre of the ovisac or inner layer of the Graafian vesicle; and it is supported in its place by the retinacula, which connect its tunica granulosa with the membrana granulosa that lines the ovisac. (See Fig. 6, Front.). The ovum then begins to move towards the periphery of the Graafian vesicle; and always towards that point of it which is nearest the surface of the ovary. This movement appears to be due, in the first instance, to the shortening of the retinacula in that direction; and whilst the ovum lies against the membrane of the ovisac, a gradual thinning of the latter seems to take place. At the same time, an important change is occurring in the outer wall of the Graafian vesicle, especially at the part most deeply imbedded in the ovary; its vascularity is greatly increased, and its substance appears thickened. This thickening is probably due to the deposition of blood in a state ready to become more highly organized, upon the exterior of the ovisac; and the consequence of it is, that considerable pressure is made upon the contents of the vesicle, the effect of which is, of course, exerted most upon the thinnest part of it. Thus, a sort of *vis a tergo* is exercised against the ovum and the disc (consisting of the tunica granulosa and the central part of the retinacula) in which it is imbedded; and the whole is forced, by the rupture of the Graafian vesicle, into the funnel-shaped entrance of the Fallopian tube,—the retinacula being gradually detached from the membrana granulosa, which is left behind. This action is represented in Fig. 8, (Front.). What becomes of the ovisac is not certain. Dr. Barry has sometimes known it to be subsequently expelled from the ovary; but it appears more commonly to remain, and to constitute the wall of the cavity which is usually found in the *corpus luteum*. The substance known under this name is found in the ovary after the ovum has escaped from it; and the importance of the question, how far its presence may be regarded as an indication that conception has taken place, requires that we should have clear ideas respecting its nature. The real corpus luteum consists of a reddish-yellow substance, glandular in aspect, friable in consistence, and very vascular, which occupies a larger or smaller part of the ovary from which the germ has escaped, according to the length of time that has elapsed since conception. At first it is usually so large, as to occasion a considerable projection on the surface of the ovary; its form is oval, or resembles that of a bean. When cut across, its dimensions are usually found to be from 4 to 5-8ths of an inch in its long diameter, and 3 to 4-8ths in its short; and it thus occupies from a fourth to a half of the whole area of the ovarium; but these dimensions are not unfrequently exceeded. The centre of this substance is hollow;

and by a proper acquaintance with this character, the true corpus luteum may be distinguished from substances bearing a general resemblance to it, but very different in their character. The following is Dr. Montgomery's account of it. "Its centre exhibits either a cavity, or a radiated or branching white line, according to the period at which the examination is made. If within the first three or four months after conception, we shall, I believe, always find the cavity still existing, and of such a size as to be capable of containing a grain of wheat at least, and very often of much greater dimensions; this cavity is surrounded by a strong white cyst [the inner coat of the Graafian vesicle, or original ovisac]; and as gestation proceeds, the opposite parts of this cyst approximate, and at length close together, by which the cavity is completely obliterated, and in its place there remains an irregular white line, whose form is best expressed by calling it radiated or stelliform. This is visible as long as any distinct trace of the corpus luteum remains."* After delivery, the size of the corpus luteum rapidly diminishes; and in a few months it ceases to be recognizable as such. The cicatrix by which the ovum has escaped is visible for some time longer; but this too, according to the careful researches of Dr. Montgomery, cannot be distinguished at a subsequent period. Hence there is no correspondence between the number of corpora lutea found in the ovaries of a woman, or of cicatrices on their surface, and the number of children she may have borne. The number of corpora lutea must always be less, when there have been many conceptions; but the number of cicatrices may be greater; for several causes, such as the escape of unimpregnated ova, or the bursting of little abscesses, may give rise to such appearances. There seems good reason to adopt Dr. Montgomery's conclusion, that the *true* corpus luteum always results from impregnation; but it is necessary that care should be taken to distinguish this from substances that are of a very different nature. The following are the characters given by Dr. M. as descriptive of the false or virgin corpora lutea.† "1. There is no prominence or enlargement of the ovary over them. 2. The external cicatrix is almost always wanting. 3. There are often several of them found in both ovaries, especially in subjects who have died of tubercular disease, such as phthisis, in which case they appear to be merely depositions of tubercle, and are frequently without any discoverable connection with the Graafian vesicles. 4. They present no trace whatever of vessels in their substance, of which they are in fact entirely destitute, and of course cannot be injected. 5. Their texture is sometimes so infirm, that it seems to be merely the remains of a coagulum; and at others appears fibro-cellular, like that of the internal structure of the ovary; but never presents the soft, rich, lobulated, and regularly glandular appearance which Hunter meant to express, when he described the true corpora lutea as 'tender and friable like glandular flesh.' 6. In figure they are often triangular, or square, or of some figure bounded by straight lines. 7. They never present either the central cavity, or the radiated or stelliform white line which results from its closure."

745. The object of the changes just described, is to bring the ovum within reach of the fecundating influence; and to convey it into the uterus after it has been fertilized. We have now to consider the changes in the ovum itself, which take place during the same epoch. At about the same period that the ovum moves towards the periphery of the Graafian vesicle, the germinal vesicle moves towards the periphery of the yelk-bag; and it always takes up its position at the precise point of the zona pellucida which is nearest the ovisac, and which is closest therefore to the surface of the ovary. Moreover,

* Signs of Pregnancy, p. 226. † Op. cit. p. 245.

the germinal spot is always on that part of the germinal vesicle, which is in closest contact with the zona pellucida. (See *a*, Figs. 9 and 10, Front.). Thus, the germinal spot is very near the exterior of the ovary; but is separated from it by the peritoneal coat of the latter, by a thin layer of its stroma forming the external layer of the Graafian vesicle, by the ovisac forming its internal membrane, and by the zona pellucida. We have already seen how the obstacle interposed by the three former to the entrance of the spermatozoon is overcome; we shall presently find that the zona pellucida undergoes a similar change. Whilst the ovum is being prepared for fecundation, a series of very important actions take place in the germinal vesicle. The exterior or peripheral portion of the spot, which previously consisted of a collection of very minute granules, begins to develope itself into a ring of new cells of extreme delicacy (Fig. 9, *a*); these gradually enlarge, and a second ring of cells is developed within it, pushing the first-formed cells further away from the centre. Many successive rings of cells are thus formed; and at last the whole germinal vesicle is filled with them, as shown at *b*, Fig. 10. Still there remains a pellucid space in the centre of the germinal spot (resembling that seen at *a*, Fig. 12), in which no cells are developed. The first-formed cells that have been pushed outwards are so much compressed by those subsequently formed, as frequently to undergo liquefaction; and during the time that the ova are being matured for fertilization, there is a continual new production of cells at the centre, and a degeneration at the circumference. At the same time, the yelk undergoes changes somewhat analogous; for it ceases to contain separate oil-globules; and large elliptical discs or cells are seen in it, especially just beneath the zona pellucida (Fig. 9, *c*).* Here, too, the formation of new cells takes place from the periphery towards the centre; the peripheral ones gradually undergo liquefaction, as is seen in the outer layer of those in Fig. 10, which are becoming indistinct; and they are replaced by a new layer pushed outwards from the centre. The same process subsequently continues in the yelk, for some time after fecundation; and this not only in regard to the yelk as a whole, but in respect to its individual cells, as is shown in Fig. 11, where concentric rings of new cells are seen in each of the parent vesicles. Even in the most advanced of these secondary cells, another generation may be seen, and these are developed upon the same plan with those of the germinal vesicle; thus in Fig. 12, the pellucid centre of the original nucleus of the parent disc is seen at *a*, and is surrounded by several concentric rings of vesicles, increasing in size from within outwards; and at *b* is represented the condition of the outer and older cells, in which the same process is undergoing repetition. (Although the figure only represents one secondary cell as in the act of producing others, the others of the same age are alike engaged in the process of multiplication.) The foregoing history is equally applicable to the cells from which the embryo subsequently originates; and it is probably the general mode in which the process takes place.

746. At the time when the interior of the germinal vesicle is being prepared for the reception of the fecundating influence, the portion of the zona pellucida against which it lies becomes attenuated; and a chink then forms in it, just above what was the pellucid centre of the germinal spot. Through this chink, the spermatozoon can reach the germinal vesicle; and that it does so, we are now entitled to affirm, not only from analogy, but also from actual observation (§ 733). What is the nature of the influence communi-

* It is to be remembered that the observations of Dr. Barry here quoted, were made on the Rabbit: and are, therefore, probably applicable equally to other Mammalia, but not to Oviparous Animals.

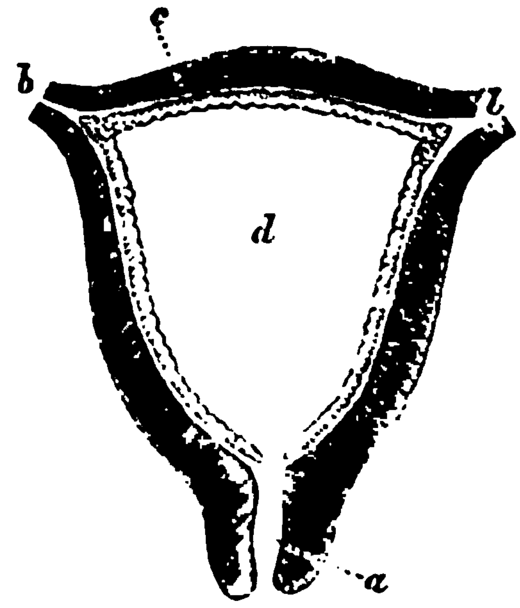
cated by it is less certain; but from the known character of the process of fecundation in Plants, we shall have little difficulty in concluding, that it deposits in the germinal vesicle the rudiments of the cells which are subsequently to be developed into the embryonic structure. It is certain that none of the cells previously contained in the germinal vesicle subsequently form part of it; in fact, they all liquefy after a time, and disappear entirely. But in the previously pellucid centre of what was the germinal spot, two new cells are seen after fecundation; these enlarge at the expense of the rest; and from them, all the permanent structures originate. This pair of cells is seen at *a*, Figs. 13 and 14; in the former some of the cells of the germinal vesicle are still left; in the latter, they have been all absorbed. The germinal vesicle returns after fecundation to the centre of the yelk, being at first entirely concealed by its discs (Fig. 11); and the cleft in the zona pellucida soon closes, so as to be no longer distinguishable. The two new cells and the other contents of the germinal vesicle, undergo such a rapid increase in size, that they soon fill the whole interior of the zona pellucida; and the cells of the yelk being reduced by the pressure into a liquid form, their elements are absorbed by the new cells of the embryonic structure. This, at least, is the case in the Mammalia; among which the yelk performs but a very subordinate part, having only to serve for the development of the embryo during a very brief period. In each of the two primary germ-cells (as they may be called) a series of changes takes place exactly conformable to that already described as occurring in the germinal vesicle;—that is to say,—a ring of new cells originates in the margin of its nucleus,—this increases in size, and is pushed outwards by another ring nearer the centre, this again by another, and so on,—and at last, two cells appear in the pellucid central space, which are developed at the expense of all the rest, and are to be regarded as the real permanent offspring of the parent. These changes may be seen in progress in Figs. 13 and 14; in the former, the original cells of the germinal vesicle have not quite disappeared, although their liquefaction is in progress; in the latter, no vestige of them is left, the whole cavity being occupied by the twin-cells.

747. These changes commence during the passage of the ovum along the Fallopian tube; and during its transit to the uterus, it receives a very important addition, that of the Chorion. This new envelope is stated by Dr. Barry to be formed at the expense of the blood-discs, which lie in great numbers on the lining membrane of the Fallopian tube at the time of conception, and which seem to have an unusual degree of vitality. When they are removed from this membrane, and are placed (with a sufficient quantity of the mucous fluid in which they are suspended) beneath the microscope, they are seen to execute for some time very remarkable movements, which cannot be referred to any cause except an inherent vitality, and which may be regarded as very analogous to those of the Spermatozoa. The movements may be seen in the bloody fluid scraped off from the lining membrane of the Fallopian tubes, and especially of their fimbriated extremity, some hours after the death of the animal, and for an hour or more after being taken out of the body. It is obvious that some purpose must be answered by this heightened vitality of the blood-corpuscles of the part; and there is certainly no *a priori* improbability in the facts stated by Dr. B. as to their transformation into the elements of the chorion. This membrane is obviously composed of cells in the first instance; and the remains of them may be frequently seen when the membrane is otherwise complete, as in Fig. 14. From the surface of the chorion, a large number of villous prolongations afterwards shoot forth; these serve as absorbing radicles, and form the channel through which the

embryo is nourished by the fluids of the parent, until a more perfect communication is formed.

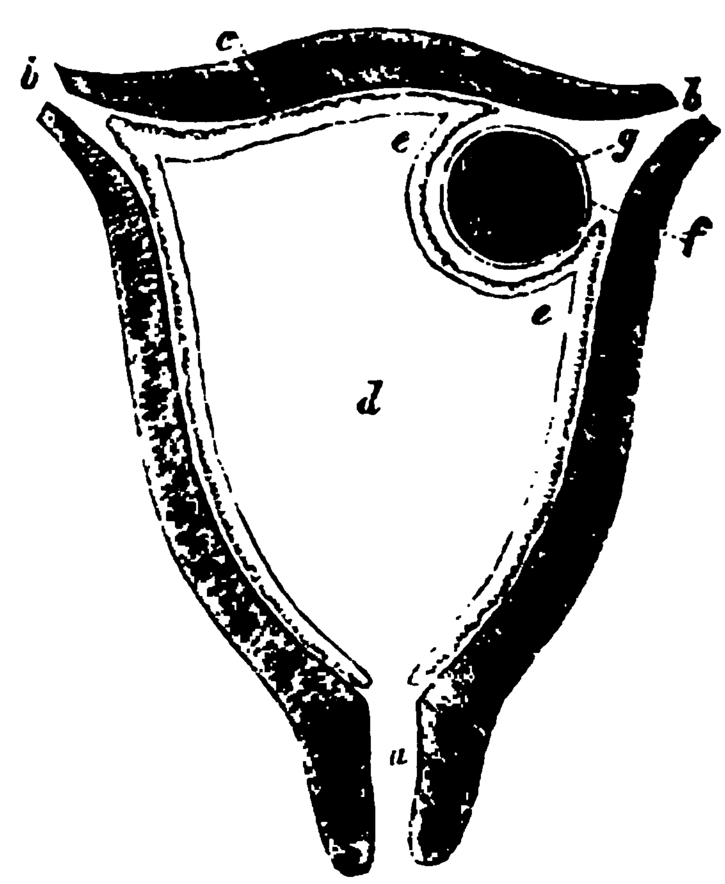
748. We have now to speak of the changes in the uterus, which take place in consequence of conception, and which prepare it to receive the ovum. Of these the most important is the formation of the membrana *decidua*, so called from its being cast off at each parturition. This membrane has been usually supposed to be a new formation; and has been described as originating in coagulable lymph thrown out on the inner surface of the uterus, into which vessels are prolonged from the subjacent surface. It appears, however, from the late researches of Dr. Sharpey and Prof. Weber,* that this is not the true account of it; and that the decidua is really composed of the inner portion of the mucous membrane itself, which undergoes a considerable change in its character. The mucous membrane of the uterus had been observed by Dr. J. Reid to possess, on its free surface, a tubular structure, not very unlike that which has been described as existing in the lining membrane of the stomach (§ 704 and Fig. 79). This tubular portion becomes thickened and increased in vascularity, within a short time after conception; and when the inner surface of a newly-impregnated uterus is examined with a low magnifying power, the orifices of its tubes are very distinctly seen, being lined with a white epithelium. The blood-vessels form a very minute network, which extend in loops from the subjacent portion of the membrane, as

Fig. 87.



Section of uterus, showing the position of the decidua vera; *a*, cervix; *b*, *b*, orifices of Fallopian tubes; *c*, decidua vera; *d*, cavity of uterus.

Fig. 88.



Section of uterus, at entrance of ovum *f*, surrounded by its chorion *g*; *a*, cervix; *b*, *b*, Fallopian tubes; *c*, decidua vera; *d*, cavity of uterus; *e*, decidua reflexa.

seen in Fig. 17 (Front.) Of the orifices of the glandular follicles, some afterwards become widened and enlarged, for the reception of the fœtal villi. The thickness of the decidua when fully formed is from one to three lines; its inner surface is smooth; whilst that in connection with the uterus is rough, in consequence of the varying length of the tubes, and of the vascular connections of the two structures. It has not yet been explained, how the decidua is formed continuously over the upper orifice of the cervix uteri, and over the orifices of the Fallopian tubes, as is frequently, though by no means

* Müller's Physiology, pp. 1574-1580.

uniformly, the case; and it seems as if a new production must *there* take place. The formation of the uterine decidua occurs whether the ovum reach the uterus or not; it being probably invariable * in cases of extra-uterine pregnancy, even though a decidua is formed around the ovum in the place of its lodgment. Besides the decidua lining the uterus, however, another membrane, continuous with this, furnishes a proper envelope to the ovum; and this has been termed the *decidua reflexa.* The formation of this is usually explained, in conformity with the account of Dr. W. Hunter, after the following manner. The ovum, on passing from the Fallopian tube into the uterus, pushes before it a portion of the decidua vera, as represented in Fig. 88; and this portion is gradually extended, by the subsequent growth of the ovum, so as at last to surround it completely. If this were precisely the case, however, the structure of the two membranes ought to be the same, which it is not; for, according to the observations of Dr. Sharpey,† the decidua reflexa is destitute, in great part of its surface, of the small orifices which characterize the vera; and these are confined chiefly, though not entirely, to a zone of the membrane surrounding the angle of reflexion, that is, to the part next the decidua vera. It would seem more probable, therefore, that the decidua reflexa is almost entirely a new production, the growth of which is simultaneous with the enlargement of the ovum; and that the decidua vera has no more share in its formation, than as supplying, through its vessels, the necessary materials. As the ovum increases in size, the decidua reflexa which covers it, comes into contact with the decidua vera, which lines the uterus; and the fluid that previously filled the cavity disappears by absorption; this usually happens during the third month. After this period, it is difficult, and frequently impossible, to distinguish the two layers; and even in aborted ova of an earlier age, the decidua reflexa is not always to be found, on a careful examination; so that its very existence has been denied by some. At one part of its surface, the ovum is covered neither by the decidua vera, nor by the decidua reflexa; this is where the former was originally detached from the wall of the uterus, by the ovum, and where it becomes continuous with the latter. It is at this point that the placenta is subsequently formed. The deficiency is supplied, however, by a new production, very analogous in structure to the decidua reflexa, and continuous with the reflected fold of the decidua vera; this is termed (from its formation being supposed to take place at a later period) the *decidua serotina* (Fig. 93, *f*).

749. The formation of the placenta commences by the penetration of the ramified villi, or filamentous processes of the chorion, into the tubuli of the decidua; the villi thus serve as roots, which suck up and convey to the embryo the nourishment secreted for it by the maternal structures. The mode in which these villi, at first consisting merely of cells, become connected with the vessels of the fœtus, will be explained hereafter. This,—the earliest and simplest mode by which the fœtus effects a new connection with the parent,—is the only one in which it ever takes place in the lower Mammalia, which are hence properly designated as "non-placental," rather than as ovo-viviparous. In the higher Mammalia, however, there soon occurs

* The doctrine of the formation of the decidua here adopted on the authority of the two accomplished anatomists mentioned above, tends to reconcile the contradictory observations which have been recorded on this interesting point; for in those cases in which nothing but an increase of thickness and sponginess in the mucous membrane of the uterus was observable, the very change was in progress in which the formation of the decidua consists.

† Loc. cit.

a great extension of the vascular tufts of the fœtal chorion, at certain points; and a corresponding adaptation, on the part of the uterine structure, to afford them an increased supply of nutritious fluid. These specially-prolonged portions are scattered, in the Ruminantia and some other Mammalia, over the whole surface of the chorion, forming what are termed the cotyledons; but in the higher orders, and in Man, they are concentrated in one spot, forming the placenta. In some of the lower tribes, the maternal and the fœtal portions of the placenta may be very easily separated; the former consisting of the thickened decidua; and the latter being composed of the prolonged and ramifying vascular tufts of the chorion, dipping down into it. But in the Human placenta, the two elements are mingled together through its whole substance. On looking at its fœtal surface, we perceive that the umbilical vessels diverge in every direction from the point at which they enter it; and their subdivisions ramify very minutely, forming a large part of its substance. The terminal ramifications are represented by Dr. J. Reid* as having the form represented in Fig. 23 (Front.), each consisting of an artery and vein bound up together; thus closely resembling the arrangement of the vessels of the gills in aquatic animals. By Weber, however, a somewhat different description of the terminations of the fœtal vessels is given; each villus being represented by him as consisting of a capillary vessel communicating with the artery and vein, and making several turns upon itself, so as to form a series of loops. It is of little practical importance which statement is the most correct; since the essential fact, that each villus contains the terminal connecting branch of an artery and a vein, is recognized in both.† The maternal portion of the placenta may be regarded, according to Dr. J. Reid, as consisting of a large sac formed by a prolongation of the inner coat of the uterine vessels; against the fœtal surface of this sac, the tufts just described may be said to push themselves, so as to dip down into it, carrying before them a portion of its thin wall, which constitutes a sheath to each tuft. In this manner, the whole interior of the placental cavity is intersected by numerous tufts of fœtal vessels, disposed in fringes, and bound down by reflexions of the delicate membrane that forms its proper wall; just as the intestines are held in their places by reflexions of the peritoneum that covers them. This view was suggested to Dr. R. by the very interesting fact, that the tufts of fœtal vessels not unfrequently extend beyond the uterine surface of the placenta, and dip down into the uterine sinuses, where they are still covered, and held in their places, by the same reflected membrane. The blood is conveyed into the placental cavity by the "curling arteries" of the uterus; and is returned from it by the large veins that are commonly designated as sinuses.‡ The fœtal vessels, being bathed in this blood, as the branchiæ of aquatic animals are in the water that surrounds them, not only enable the fœtal blood to exchange its venous character for the arterial, by parting with its carbonic acid to the maternal blood, and receiving oxygen from it; but they also serve as rootlets, by which certain nutritious elements of the maternal blood (probably those composing the liquor sanguinis) are taken into the system of the fœtus. There is no more direct communication between the mother and fœtus than this; all the observations which have been supposed to prove the existence of real vascular continuity, having been

* Edinburgh Med. and Surg. Journal, Jan. 1841.

† It has been suggested to the Author by his friend Dr. J. Reid, that the appearances described by Weber, and more recently by Mr. Dalrymple, are due to the vessels having been over-distended by injection; his own view being founded upon observations upon villi that had been but moderately distended.

‡ A plan of Dr. Reid's idea of this structure is shown in Fig. 24 [Front.].

falsified by the extravasation of fluid, consequent upon the force used in injecting the vessels. Moreover the different size of the blood-corpuscles in the fœtus and in the parent (§ 477) shows the non-existence of any such communication. That the placenta is not absolutely necessary to the nutrition of the Human fœtus, any more than to that of the non-placental Mammalia, is a doctrine that has been maintained by several physiologists of eminence, in consequence of the not very unfrequent occurrence of cases in which it has been very imperfectly formed, so as to be manifestly unfit, at least in great degree, for the performance of its functions;* and it cannot but be admitted, that there is much evidence in support of this view. In those cases, however, in which the placenta has been from the first imperfectly formed, the nutrition of the fœtus has manifestly suffered; whilst in those in which a degeneration of its structure has taken place (as by the deposition of calcareous matter), there is no evidence that, up to a late period of pregnancy, the fœtus may not have been nourished through its means. Where the placental structure is so abnormal, that it cannot be imagined to be subservient to its proper function, we must suppose the nutrition of the fœtus to take place through the medium of the liquor amnii, which is probably absorbed by its cutaneous vessels.

750. The formation of the placenta, in the manner just described, commences in the latter part of the second month; during the third, it acquires its proper character; and it subsequently goes on increasing, in accordance with the growth of the ovum. Towards the end of the term of gestation, however, it becomes more dense and less vascular; owing, it would seem, to the obliteration of several of the minuter vessels, which are converted into hard fibrous filaments. The vessels of the uterus undergo great enlargement throughout, but especially at the part to which the placenta is attached; and the blood in moving through them produces a peculiar murmur, which is usually distinctly audible at an early period of pregnancy, and may be regarded (when due care is taken to avoid sources of fallacy) as one of its most unequivocal positive signs. The placental bruit is thus described by Dr. Montgomery.† "The characters of this phenomenon are, a low murmuring or somewhat cooing sound, resembling that made by blowing gently over the lip of a wide-mouthed phial, and accompanied by a slight rushing noise, but without any sensation of impulse. The sound is, in its returns, exactly synchronous with the pulse of the mother at the time of examination; and varies in the frequency of its repetitions, with any accidental variation which may occur in the maternal circulation. Its situation does not vary during the course of the same pregnancy; but in whatever region of the uterus it is first heard, it will in future be found, if recognized at all,—for it is liable to intermissions,—at least we shall occasionally be unable to hear it where we have already heard it a short time before, and where we shall shortly again recognize it. According to my experience, it will be most frequently heard about the situation of the Fallopian tube of the right side; but it may be detected in any of the lateral or anterior parts of the uterus." That the cause of this sound exists in the uterus itself, is distinctly proved by the fact, that it has been heard when the uterus was so completely *anteverted*, that the fundus hung down between the patient's thighs. A sound so much resembling this as to be scarcely distinguishable from it, may be occasioned, however, by a cause of a very different nature,—namely, an abdominal tumour, pressing upon the aorta, iliac arteries, or enlarged vessels

* For a collection of such cases, see Dr. Dunglison's Physiology, Vol. II.
† Op. cit. p. 121.

of its own; and, in doubtful cases, it is necessary to give full weight to the possibility of such an explanation. The sound may be imitated at any time, by pressing the stethoscope on the iliac arteries. The placental bruit has been not unfrequently heard in the 11th week; but it cannot generally be detected before the fourth month, when the fundus uteri rises above the anterior wall of the pelvis.

751. The amount of the peculiar tissue of the uterus (§ 375) greatly increases during pregnancy; and from the recent observations of Dr. R. Lee, it appears that a corresponding increase takes place in the size of the nervous ganglia. At the same time the Mammary gland and its appendages undergo a fuller development; and from this a valuable, but not unequivocal, indication of pregnancy may be drawn. Occasional shooting pains in the mammæ are not unfrequently experienced within a short period after conception; and more continued tenderness is also not unusual. A sense of distension is very commonly experienced at about the end of the second month; and from that time a distinct "knottiness" usually begins to present itself, increasing with the advance of pregnancy. In many instances, however, these mammary sympathies are entirely absent, and they may be stimulated by changes that take place in consequence of various affections of the uterus. A change of colour in the areola is a very common but not an invariable occurrence in the early months of pregnancy; but another sign is afforded by the areola and nipple, which is of more value because more constant,—namely, a puffy turgescence, and an increased development of the little glandular follicles, or tubercles, which commonly secrete a dewy moisture. The presence or absence of *kiesteine* in the urine (§ 690) may probably be regarded as one of the best diagnostic signs we possess.* This substance appears on the surface of the fluid, after it has stood two or three days, in the form of a thin pellicle of a somewhat fatty aspect; it is preceded by a sediment which has very much the appearance of cotton wool; and it disappears when the urine is decomposing, at the same time emitting an odour like that of putrid cheese. Many other changes in the constitution take place during pregnancy, indicated by the buffiness of the blood, the irritability of the stomach, and the increased excitability of the mind. All these, however, are discussed with sufficient amplification, in works on Obstetric Medicine.

752. The act of Conception, being one of a purely organic nature, is not attended with any consciousness on the part of the mother; but there are some women in whom it is attended with certain sympathetic affections, such as faintness, vertigo, &c., that enable them to fix upon the particular time at which it has taken place. From that period, however, the mother has no consciousness of the change going on in the uterus; until the occurrence of what is termed "quickening." This is generally described as a kind of fluttering movement, attended with some degree of syncope or vertigo. After it has once occurred, and has strongly excited attention, it is occasionally renewed once or twice, and then gives place to the ordinary movements of the fœtus. Not unfrequently, however, no movement whatever is felt, until near the end of the term of gestation, or even through the whole of it. As to the cause of the sensation, Obstetricians are much divided; and no satisfactory account has been given of it. It has been vulgarly supposed to be due to the first movement of the fœtus, which was imagined then to become possessed of an independent life; and the English law recognizes the truth of this doctrine, in varying the punishment of an

* {See an excellent paper on this subject in the American Journal of Medical Sciences, No. VII., N. S. By Dr. Elisha Kane.—M. C.}

attempt to procure abortion, according to whether the woman be "quick with child" or not; and in delaying execution when a woman can be proved to be so; though it is made to proceed if she is not, even if she be unquestionably pregnant. Whether or not the first *sensible* motions of the fœtus are the cause of the peculiar feeling in question, there can be no doubt that the embryo has as much independent vitality before, as after, the quickening. From the time that the ovum quits the ovary, it ceases to be a part of the parent, and is dependent on it only for a due supply of nourishment, which it converts, by its own inherent powers, into its proper fabric. This dependence cannot be said to cease at the moment of quickening; for the connection must be prolonged several weeks, before the fœtus can be said to be capable of living without such assistance. The earliest period at which this may occur, will be presently considered.

753. At the conclusion of about nine (solar) months from the period of conception, the time of parturition arrives. The uterus, by its own efforts, and by the assistance of the diaphragm and abdominal muscles, expels its contents; and the membranes of the ovum being usually ruptured before it is entirely discharged, the fœtus comes at once into the world. Respecting the degree in which the parturient efforts are probably dependent on nervous influence, some remarks have been already made (§ 203). It seems by no means unlikely, that the uterus, though not itself dependent upon the spinal cord for its power of contraction, may contain numerous afferent or *excitor* fibres; and that these, being compressed by the efforts of its own muscular structure, may propagate to the spinal cord the stimulus necessary for the consentaneous action of the assistant muscles. Those who may watch a labour, with an attentive consideration of its phenomena, will find that the "pains" usually commence in the uterus itself, and that it is only when they become decided, that the power of the other muscles is called into operation. As to the reason why the period of parturition should be just nine months after that of conception, we know nothing more than we do of that of similar facts in the physical history of Man,—such as the periodical return of the catamenia, the renewal of the teeth,—the recurrence of the tendency to sleep, &c. That it is immediately dependent upon some state of the constitution, rather than upon the condition of the uterus, appears from the fact that, in cases of extra-uterine pregnancy, contractions resembling those of labour take place in its walls. Moreover, various states of the constitution, especially that which is designated as irritability, may induce the occurrence of the parturient efforts at an earlier period; and this constitutes abortion or premature delivery, according to the *viability* of the child. There are some women, in whom this regularly happens at a certain month, so that it seems to be an action natural to them; but it is always to be prevented, if possible, being injurious alike to the mother and child; and this prevention is to be attempted by rest and tranquillity of mind and body, and by a careful avoidance of all the exciting causes, which may produce uterine contractions by their operation on the nervous system. For it is to be remembered that, although the muscular fibres of the uterus are capable, like those of the alimentary canal, of an independent action, they are likely to be excited to operation through the nervous system, and especially through the sympathetic (§ 203). The same action which expels the fœtus also detaches the placenta; and if the uterus contract with sufficient force after this has been thrown off, the orifices of the vessels which communicated with it are so effectually closed, that little or no hemorrhage takes place. If, however, the uterus does not contract, or relaxes after having contracted, a large amount of blood may be lost in a short time from the open orifices. For some little time after parturition, a sero-sanguineous

discharge termed the lochia, is poured out from the uterus; and this commonly contains shreds of the deciduous membrane, which had not been previously detached. Within a few weeks after delivery, the uterus regains (at least in a healthy subject) its previous condition; and it is probable that the portion of its mucous membrane which had been thrown off as decidua, is very early reproduced.

754. The duration of pregnancy is commonly stated at nine solar months; but it would be more correct to fix the period at 40 weeks, or 280 days, which exceeds nine months by from 5 to 7 days, according to the months included. This, at least, is the average result of observation, in cases in which the period of conception could be fixed, from peculiar circumstances, with something like certainty. The mode of reckoning customary among women, is to date from the middle of the month after the last appearance of the catamenia; but it is certain that conception is much more likely to take place *soon* after they have ceased to flow, than at a later period (§ 472, *n.*); so that, in most instances, it would be most correct to expect labour at forty weeks and a few days after the last recurrence of the menses. The period of quickening may be relied on in some women, in whom it occurs with great regularity in a certain week of pregnancy; but there is in general great latitude as to the time of its occurrence. The usual or average time is probably about the 18th week.

755. The question of the extreme limits of gestation, is one of great importance both to the practitioner and to the medical jurist; but it is one which cannot yet be regarded as satisfactorily decided. Many persons, whose experience should give much weight to their opinion, maintain that the regular period of 40 weeks is never extended for more than two or three days; whilst, on the other hand, there are numerous cases on record, which, if testimony is to be believed at all (and in many of these, the character and circumstances of the parties placed them above suspicion), furnish ample evidence that gestation may be prolonged for at least three weeks beyond the regular term.* The English law fixes no precise limit; and the decisions which have been given in our courts, when questions of this kind have been raised, have been mostly formed upon the collateral circumstances. The law of France provides that the legitimacy of a child born within 300 days after the death or departure of the husband shall not be questioned; and a child born after more than 300 days is not declared a bastard, but its legitimacy may be contested. By the Scotch law, a child is not declared a bastard, unless born after the tenth month from the death or departure of the husband. The analogical evidence drawn from observations on the lower animals is extremely strong. The observations of Tessier, which were continued during a period of forty years, with every precaution against inaccuracy, have furnished a body of results, which seems quite decisive. In the Cow, the ordinary period of gestation is about the same as in the Human female; but out of 577 individuals, no less than 20 calved beyond the 298th day, and of these, some went on to the 321st, making an excess of nearly six weeks. Of 447 Mares, whose natural period of gestation is about 335 days, 42 foaled between the 359th and the 419th day, the greatest protraction being thus 84 days, or just one-fourth of the usual term. Of 912 Sheep, whose natural period is about 151 days, 96 yeaned beyond the 153d day; and of these, 7 went on until the 157th day, making an excess of 6 days. Of 161 Rabbits, whose natural period is about 30 days, no fewer than 25 littered between the 32d and

* A good collection of such cases will be found in Dr. Montgomery's excellent work on the Signs of Pregnancy.

35th; the greatest protraction was here one-sixth of the whole period, and the proportion in which there was a manifest prolongation was also nearly one-sixth of the total number of individuals. With regard to incubation, Tessier found that there was not unfrequently a prolongation to the amount of 3 days, or one-seventh of the whole period, in the case of the common Hen. In regard to Cows, the observations of Tessier have been recently confirmed by those of Earl Spencer, who has published* a table of the period of gestation as observed in 764 individuals; he considers the average period to be 284 or 285 days: but no fewer than 310 calved after the 285th day; and of these, 3 went on to the 306th day, and 1 to the 313th. It is curious that, among the calves born between the 290th and 300th days, there was a decided preponderance of males,—these being 74, to 32 females; whilst all of those born after the 300th day were females. These variations are probably to be regarded as due, not so much to a prolongation of the period of *utero*-gestation, as to various circumstances which may have a retarding influence on the process of fecundation, and on the transmission of the ovum through the Fallopian tube. These have been well pointed out by Dr. Montgomery.† It may be added that in Dr. Barry's observations on the early changes that take place in the ovum of Rabbits, he has noticed several irregularities of this description. On the whole, it may be considered that, in regard to the Human female, the French law is a very reasonable one. It is probable, from the circumstances alluded to in the preceding paragraph, that gestation is protracted to the extent of a week, ten days, or a fortnight, much more frequently than is commonly supposed. In several of the cases in which the protraction appeared indubitable, the infant was unusually large and vigorous.

756. In regard to the shortest period at which gestation may terminate consistently with the viability of the child, there is a still greater degree of uncertainty. Most practitioners are of opinion that it is next to impossible for a child to live and grow to maturity, which has not almost completed its seventh month; but it is almost unquestionable that infants which have been born at a much earlier period, have lived for some months. It is rare in such cases, however, that the date of conception can be fixed with sufficient precision, to enable a definite statement to be given. Of the importance of the question, a case which recently occurred in Scotland affords sufficient proof. A vast amount of contradictory evidence was adduced on this trial; but, on the general rule of accepting positive in preference to negative testimony, it seems that we ought to consider it possible that a child may live for some months, which has been born at the conclusion of 24 weeks of gestation. In the case in question, the Presbytery decided in favour of the legitimacy of an infant born alive within 25 weeks after marriage. A very interesting case is on record,‡ in which the mother (who had borne five children) was confident that her period of gestation was less than 19 weeks; the facts stated respecting the development of the child are necessarily very imperfect, as it was important to avoid exposing his body, in order that his temperature might be kept up; but at the age of three weeks, he was only 13 inches in length, and his weight was no more than 29 oz. At that time, he might be regarded, according to the calculation of the mother, as corresponding with an infant of 22 weeks or 5½ months; but the length and weight were greater than is usual at that period, and he must have been

* Journal of the English Agricultural Society, 1839.
† Op. cit. p. 272.
‡ Edinb. Med. and Surg. Journal, Vol. xi.

probably born at about the 25th week. It is an interesting feature in this case, that the calorific power of the infant was so low, that artificial heat was constantly needed to sustain it; but that, under the influence of the heat of the fire, he evidently became weaker, whilst the warmth of a person in bed rendered him lively and comparatively strong. During the first week, it was extremely difficult to get him to swallow; and it was nearly a month before he could suck. At the time of the report, he was four months old, and his health appeared very good. Another case of very early viability has been more recently put on record by Mr. Dodd:* in this, as in the former instance, the determination of the child's age rests chiefly on the opinion of the mother; but there appears no reason for suspecting any fallacy. The child seems to have been born at the 26th or 27th week of gestation; and having been placed under judicious management, it has thriven well. One of the most satisfactory cases on record is that recorded by Dr. Outrepont (Professor of Obstetrics at Wurtzburgh), and stated by Dr. Christison in his evidence on the case just alluded to.† The evidence is as complete as it is possible to be in any case of the kind; being derived not only from the date assigned by the mother to her conception, but also from the structure and history of the child. The gestation could have only lasted 27 weeks, and was very probably less. The length of the child was 13½ inches, and its weight was 24 oz. Its development was altogether slow; and at the age of 11 years, the child seemed no more advanced in body or mind, than most other lads of seven years old. In this last point, there is a very striking correspondence with the results of other observations upon very premature children, made at an earlier age; and these all harmonize with the general principle already more than once alluded to,—that, the shorter the period during which the early development of the embryo takes place at the expense of nourishment supplied by the parent, the lower is the degree of development it will ultimately attain (§ 54).

756. There is another question regarding the function of the Female in the reproductive act, which is of great interest in a scientific point of view, and which may become of importance in juridical inquiries,—namely, the possibility of *superfœtation*, that is, of two distinct conceptions at an interval of considerable length, so that two fœtuses of different ages, the offspring perhaps of different parents, may exist in the uterus at the same time. The simplest case of superfœtation, the frequent occurrence of which places it beyond reasonable doubt, is that in which a female has intercourse on the same day with two males of different complexions, and bears twins at the full time, the two infants resembling the two parents respectively. Thus, in the slave-states of America, it is not uncommon for a black woman to bear at the same time a black and a mulatto child; the former being the offspring of her black husband, and the latter of her white paramour. The converse has occasionally, though less frequently, occurred; a white woman bearing at the same time a white and a mulatto child. There is no difficulty in accounting for such facts, when it is remembered that nothing has occurred to prevent the uterus and ovaria from being as ready for the second conception as for the first; since the orifice of the former is not yet closed up; and, at the time when one ovum is matured for fecundation, there are usually more in the same condition. But it is not easy thus to account for the birth of two children, each apparently mature, at an interval of five or six months; since it might have been supposed that the uterus was so com-

* Provincial Medical and Surgical Journal, Vol. II. p. 474.
† Record of Proceedings against the Rev. Fergus Jardine, Edin. 1839.

pletely occupied with the first ovum, as not to allow of the transmission of the seminal fluid necessary for the fecundation of the second. In cases where two children have been produced at the same time, one of which was fully-formed, whilst the other was small and seemingly premature, there is no occasion whatever to imagine that the two were conceived at different periods, since the smaller fœtus may have been "blighted," and its development retarded, as not unfrequently happens in other cases. Nor is it necessary to infer the occurrence of superfœtation in every case, in which a living child has been produced a month or two after the birth of another; since the latter may have been premature, whilst the former has been carried to the full term. But such a difference can scarcely be, at the most, more than 2½ or three months, and there are several cases now on record, in which the interval was from 110 to 170 days, whilst neither of the children were premature in appearance; so that the possibility of a second conception, when the uterus already contains an ovum of several months, can scarcely be denied, however improbable it may seem.

Development of the Embryo.

757. Under this head it is intended to state, not so much the details of the process of development, as those leading facts, the knowledge of which is desirable in itself, as well as essential to the due comprehension of the former. It is difficult to see what practical benefit can result from a minute acquaintance with all the steps of the evolution of the embryo, however interesting these may be in a scientific point of view; and the time of the ordinary student, on which there are so many pressing calls, may be much better occupied than in committing them to memory. In the following sketch, little will be said respecting the latter stages of the process, or on the development of particular organs, since these have been already noticed under their severally distinct heads. Our attention will first be given to the formation of the embryonic mass, and of the membranes surrounding the yelk-bag; and then to the origin of the vertebral column, digestive organs, and circulating apparatus.

758. The ovum, when it quits the ovarium, has been stated to contain within the germinal vesicle, two cells which did not exist there previously to fecundation; and from each of these, two new cells are subsequently produced, which in their turn give birth to eight others. In this manner, the number of vesicles originating in the twin-cells of the germ is continually increased, until at last they become too numerous to be counted, and form a cluster resembling a mulberry in appearance; this mulberry-like structure may be conveniently termed the *germinal mass* (Front. Fig. 15, *a*). In the centre of this mass there is found a peculiar cell, differing from the rest in its greater size, and in possessing a very well-defined annular nucleus, with a pellucid cavity in its centre (Fig. 16, *a*, *b*). From this peculiar cell, all the parts which enter permanently into the composition of the embryo are developed; the vesicles forming the exterior of the germinal mass being subservient to a merely temporary purpose. This central or embryonic cell is gradually brought to the surface of the germinal mass, by the formation of a cavity (*c*) in the interior of the latter; for the layer of cells within which this cavity is formed, progressively extends itself, until it comes into contact with the inner surface of the yelk-bag, having absorbed the yelk into the hollow thus left. Thus out of the periphery of the mulberry-mass, is formed the exterior layer of what is termed the *germinal membrane:* this membrane is first seen as an epithelium-like layer of cells, covering the yelk;

but beneath this layer, which is afterwards known as the *serous* lamina of the germinal membrane, two others are subsequently produced from the central portion of the germinal mass. Now it is highly interesting to observe, that this germinal membrane, which in the higher animals is a mere temporary structure, subservient only to a temporary function, forms, in the lower tribes, the greater part of the permanent fabric of the body. Thus, in the Polypes, the cavity in which the yelk is enclosed becomes a stomach; the external layer of the germinal membrane becomes the integument; whilst the internal forms the lining of the digestive cavity, of which the mouth is formed by absorption of its wall at one point. Here the yelk is directly absorbed and assimilated by the surrounding membrane. In the higher Oviparous animals, the germinal membrane serves to absorb nutritious matter from the yelk, and to prepare it for the use of the embryo itself by converting it into blood (§ 577); but, after the yelk has been exhausted, the yelk-bag is taken into the body, and is gradually removed by absorption. In Mammalia, these structures are of less importance. The store of yelk laid up for the nutrition of the embryo is comparatively inconsiderable, being only destined to serve for the short time that elapses, before the ovum forms its new connection with the parent, through the medium of the chorion; and the yelk-bag is ultimately separated from the embryo, and thrown off as useless. Still the early processes are the same in Mammiferous, as they are in Oviparous animals; and the development of Man, of a Bird, of a Reptile, or of a Fish, takes place, up to a certain point, upon the same general plan.

759. The embryonic cell, and the cluster of cells that surrounds it, having arrived on the surface of the yelk by the movemeut just described, constitute what is known in the Bird's egg under the name of the *cicatricula.* This is a semi-opaque disc, composed of numerous flattened cells; and in the midst of it is seen a round transparent space, termed the *area pellucida,* which is nothing else than the place occupied by the large embryonic cell, now become flattened, and still retaining its clearness. In the centre of this is seen a very faint line, which is termed the *primitive trace;* and this is the large annular nucleus (Fig. 16, *b*) of the embryonic cell, now become elongated, and beginning to be developed into cells. The same process then takes place within the embryonic cell, which has been described as occurring within the germinal vesicle (§ 745); the granules forming the periphery of the nucleus are first developed into cells, and these are pushed outwards by a new series subsequently generated nearer the centre. From the mass of cells thus formed, a hollow process passes down into the yelk; and this gradually extends itself, in the same manner as did that formed from the mulberry-mass, until it includes the whole yelk, and comes into contact with the inner surface of the layer of cells already mentioned as forming the serous or external lamina of the germinal membrane. This second layer of cells is probably that which forms the *vascular* lamina of the germinal membrane. A third process seems to be afterwards sent down from a part of the nucleus somewhat interior to that from which the last proceeded; and this becomes the *mucous* or internal lamina of the germinal membrane.*

* This account of the formation of the germinal membrane, which is derived from Dr. Barry's Embryological Researches on the Rabbit, differs considerably from that which has been given by previous authors as to the result of their observations on the ovum of the Bird. But there are many reasons which induce the Author to feel satisfied that Dr. B.'s history is in the main correct; and he has recently learned from that gentleman, that he has received from Prof. Wagner, one of the highest authorities on the subject, an expression of his general accordance with it.

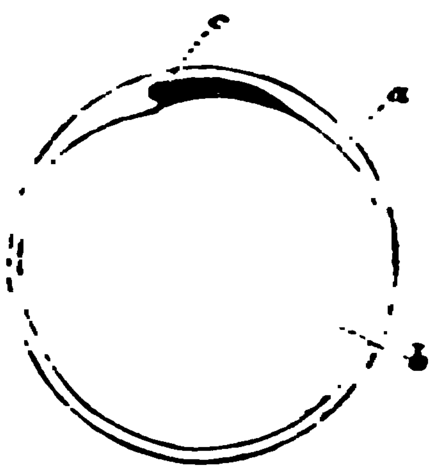
760. The cell-germs forming the periphery of the nucleus having been thus developed, those nearer the centre then begin to exhibit a corresponding activity. Their evolution follows exactly the same plan as that which has been described in regard to the contents of the germinal vesicle (§ 745); with the exception that these are arranged in an elongated and not in a circular form. The shape of the nucleus at this time may be compared to that of a pear of which the lower part is very narrow; the large end marks the situation of the head; whilst the prolonged portion is the rudiment of the spinal column. From the portion of it nearest to the median line, and therefore developed into cells later than the rest, the nervous centres are evolved; these are surrounded by a tubular structure, which has but a temporary existence in the higher Vertebrata, but which is permanent in the lower Fishes. This structure, termed the *chorda dorsalis*, is found, wherever it exists, to be entirely composed of nucleated cells. From the cells which are exterior to these, is produced the vertebral column; and the mode in which this originates is somewhat as follows. The cells on either side of the central space (in which the elements of the nervous system are not yet developed) rise up in a ridge, so that the central space becomes a groove; these two ridges gradually rise up and approach one another, and they are then observed to contain, in what subsequently becomes the thoracic region, a few pairs of small opaque plates. The ridges (termed *plicæ dorsales*, or dorsal laminæ) continue inclining towards each other, until they coalesce, so that a complete tube is formed; and in this tube an indication is soon perceived of a division into vertebræ, of which the plates just mentioned are the incipient arches. Towards the anterior extremity, however, the dorsal laminæ do not at once close in; and the large cells in which the great divisions of the encephalon originate (§ 214) may be seen between them. From the dorsal laminæ on either side, a prolongation passes outwards and then downwards, forming what is known as the *ventral lamina;* in this are developed the ribs and the transverse processes of the vertebræ; and the two have the same tendency to meet on the median line, and thus to close in the abdominal cavity, which the dorsal laminæ have to enclose the spinal cord. At the same time the layers of the germinal membrane which lie beyond the extremities of the embryo are folded in, so as to make a depression on the yelk; and their folded margins gradually approach one another under the abdomen. In these two modes, a cavity is formed beneath the embryonic mass, which is separated from the general cavity of the yelk by the folds just described; but these still leave a passage which, in the Bird, remains of considerable size until a much later period, but which, in the Mammiferous ovum, is soon obliterated. For the sac which contains the yelk, and from which the abdominal cavity is pinched off, as it were, at a very early period, is destined, in the Mammiferous animal, to be entirely cast away; the purpose which it has to serve being one of a very temporary character.

761. Whilst these new structures are being produced, a very remarkable change is taking place in that part of the serous lamina which surrounds the area pellucida. This rises up on either side in two folds; and these gradually approach one another, at last meeting in the space between the general envelope and the embryo, and thus forming an additional investment to the latter. As each fold contains two layers of membrane, a double envelope is thus formed; of this, the outer lamina adheres to the general envelope; whilst the inner remains as a distinct sac, to which the name of *amnion* is given. (See Figs. 91, 92 and 93.) This takes place during the third day in the Chick; the period at which it occurs in the Human ovum is difficult to

be ascertained, owing to the small number of normal specimens wh[illegible] come under observation at a sufficiently early period.

762. During the same period, a very important provision for th[illegible] support of the embryo begins to be made, by the development o[illegible] vessels, and the formation of blood. Hitherto, the embryonic stru[illegible]

Fig. 89.



Plan of early uterine ovum. Within the external ring, or zona pellucida, are the serous lamina, a; the yolk, b; and the incipient embryo, c.

Fig. 90.

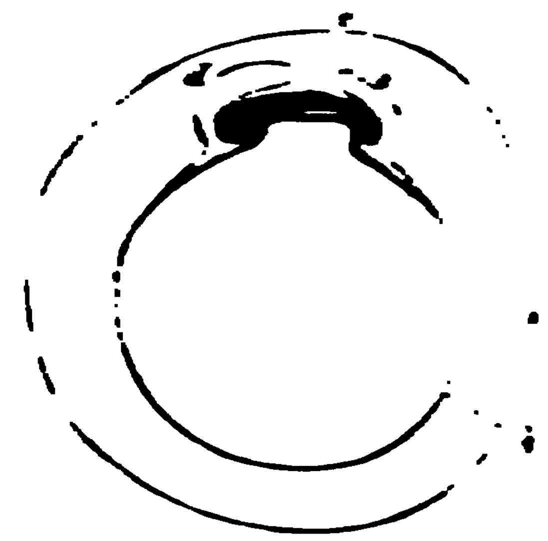


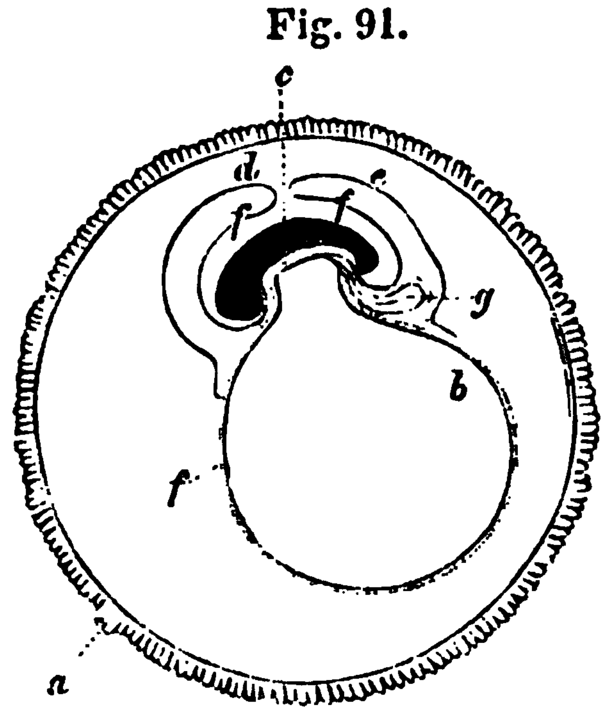
Diagram of ovum at later stage, [illegible] cavity beginning to be separated from [illegible] sac, and amnion beginning to be form[illegible] chorion; b, yolk-sac; c, embryo.

been nourished by direct absorption of the alimentary materials suppli[illegible] it by the yolk; in the same manner as the simplest cellular plant [illegible] loped at the expense of the carbonic acid, moisture, &c., which it obtai[illegible] itself from the surrounding elements. But its increasing size, and the ne[illegible] sity for a more free communication between its parts than any structure [illegible] sisting of cells alone can permit, calls for the development of vessels, [illegible] which the nutritious fluid may be conveyed. These vessels are fir[illegible] in that part of the vascular lamina of the germinal membrane, which imme[illegible] diately surrounds the embryo; and they form a network, bounded by [illegible] cular channel, which is known under the name of the [illegible] and gradually extends itself, until the vessels spread over the whole membrane surrounding the yolk. The first blood-discs appear [illegible] from the nuclei of the cells, whose cavities have become [illegible] each other to form the vessels (577); and from these, all subsequent discs are probably generated. This network of blood-vessels [illegible] purpose of absorbing the nutritious matter of the yolk, and of [illegible] towards the embryonic structures, which are now in process of development. The first movement of the fluid is towards the embryo; and can be witnessed before any distinct heart is evolved. The [illegible] [illegible]

vert it into matter fit for the nutrition of the young plant, of which they form a temporary part.

763. The formation of the heart takes place in the vascular layer, beneath the upper part of the spinal column; it at first appears as a mere cavity in its substance, surrounded only by cells; but its walls gradually acquire firmness and distinctness, and become sufficiently powerful to propel the blood through the vessels of the embryo and those of the vascular area. The first appearance of the heart in the Chick is at about the 27th hour; the time of its formation in Mammalia has not been distinctly ascertained. In its earliest form it has the same simple character which is presented by the central impelling cavity of the lower Invertebrata; being a mere prolonged canal, which at its posterior extremity receives the veins, and its anterior sends forth the arteries. After a short time, however, it becomes bent upon itself; and it is then subdivided into three cavities, which exist in all Vertebrata,—a simple auricle or receiving cavity, a simple ventricle or propelling cavity, and a bulbus arteriosus at the origin of the aorta. The circulation is at first carried on exactly upon the plan, which is permanently exhibited by Fishes. The aorta subdivides into four or five arches on either side of the neck; and these are separated by slits or fissures, much resembling those which form the entrance to the gill-cavities of Cartilaginous Fishes. These arches reunite to form the descending aorta, which transmits branches to all parts of the body. Such is the first phase or aspect of the circulating apparatus, which is common to all Vertebrata during the earliest period of their development, and which may therefore be considered as its most general form. It remains permanent in the class of Fishes; and in them the vascular system undergoes further development on the same type, a number of minute tufts being sent forth from each of the arches, which enter the filaments of the gills, and serve for the aeration of the blood. In higher Vertebrata, however, the plan of the circulation is afterwards entirely changed, by the formation of new cavities in the heart, and by the production of new vessels; these changes will be presently described. It is incorrect, therefore, to speak of the vascular arches in *their* necks as *branchial* arches, since no branchiæ or gills are ever developed from them. The clefts be-

Fig. 91.



The amnion in process of formation, by the arching over of the serous lamina: *a*, the chorion; *b*, the yelk-bag, surrounded by serous and vascular laminæ; *c*, the embryo; *d*, *e*, and *f*, external and internal folds of the serous layer, forming the amnion; *g*, incipient allantois.

Fig. 92.

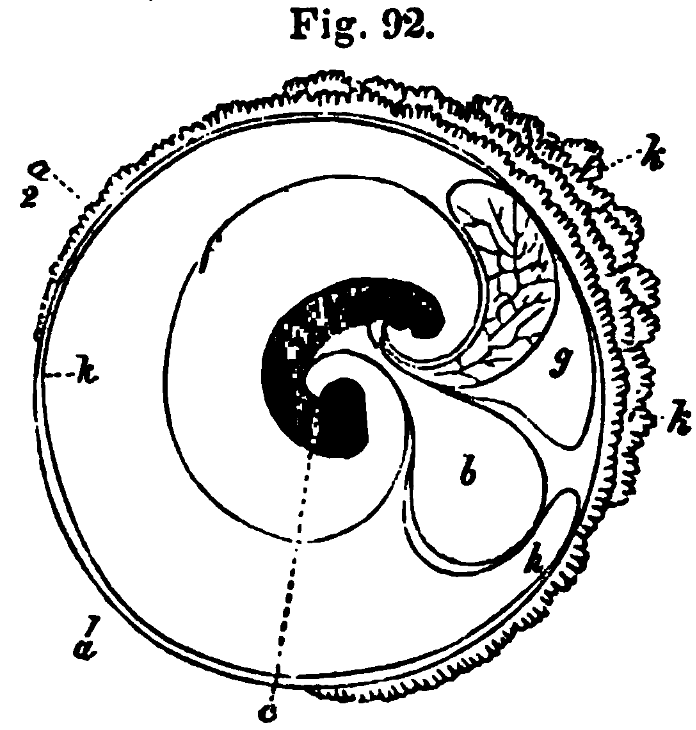


Diagram representing a human ovum in second month: *a*, 1, smooth portion of chorion; *a*, 2, villous portion of chorion; *k*, *k*, elongated villi, beginning to collect into placenta; *b*, yelk-sac or umbilical vesicle; *e*, embryo; *f*, amnion (inner layer); *g*, allantois; *h*, outer layer of amnion, coalescing with chorion.

take a share in this function (§ 466). The temporary
now to be described, bears a strong resemblance in its
especially in its vascular connections, with the gills of
are prolongations of the external surface (usually near th
intestinal canal), and which almost invariably receive th
part of the system. This apparatus is termed the *allanto*
of a kind of diverticulum or prolongation of the lower
cavity, the formation of which has been already described.
as a simple vesicle, of no great size (Fig. 91, *g*); and in the
which is soon provided with other means of aerating its bl
any considerable dimensions. In Birds, however, it be
extend itself around the whole yelk-sac, intervening betw
brane of the shell; and through the latter it comes in
external air. The accompanying diagram will serve to e
position in the Human ovum. The chief office of the al
is to convey the vessels of the embryo to the chorion; a
pretty close correspondence with the extent of surface
chorion comes into vascular connection with the deci
Carnivora, whose placenta extends like a band around t
allantois also lines the whole inner surface of the chorio
umbilical vesicle comes in contact with it. On the other
Quadrumana, whose placenta is restricted to one spot, t
and conveys the fœtal vessels to one portion only of t
these vessels have reached the chorion, they ramify i
send filaments into its villi; and in proportion as these
nection with the uterine structures which has been alrea
vessels increase in size. They then pass directly fro
chorion; and the allantois, being no longer of any use,
mains as a minute vesicle, only to be detected by careful
same thing happens in regard to the umbilical vesicle, fr
contents have been by this time exhausted; and from hen
entirely dependent for the materials of its growth, upon t
through the placenta, which is conducted to it by the ves
cord. This state of things is represented in the acco

receives an investment from the amnion, which forms a kind of tubular sheath around it; it is continuous at the umbilicus with the integument of the fœtus; and at the point where the cord enters the placenta, it is reflected

Fig. 93.

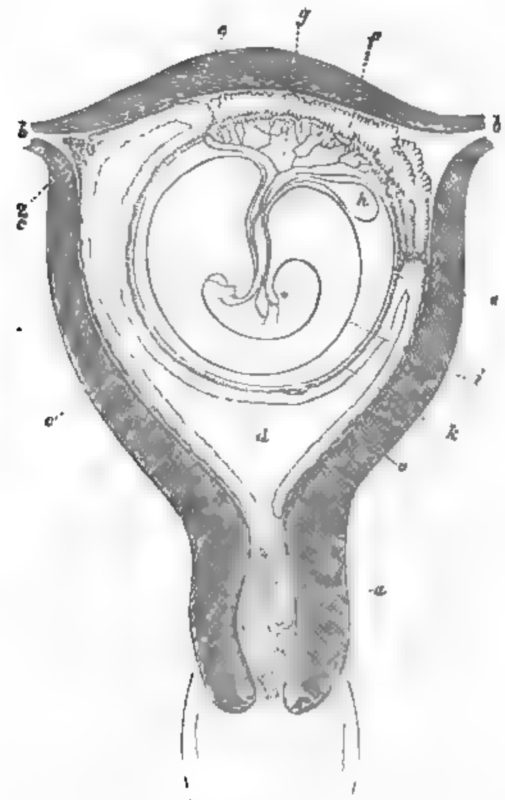


Diagram of Human Ovum, at the time of formation of placenta; *a*, muco-gelatinous substance, blocking up os uteri; *b*, *b*, Fallopian tubes; *c*, *c*, decidua vera, prolonged at *c* 2, into Fallopian tube; *d*, cavity of uterus, almost completely occupied by ovum (compare with Fig. 88). *e*, *e*, angles at which decidua vera is reflected; *f*, decidua serotina; *g*, allantois; *h*, umbilical vesicle; *i*, amnion; *k*, chorion, lined with outer fold of serous tunic (§ 762).

over its internal or fœtal surface. The amnion contains a fluid known as the *liquor amnii*, which consists of water holding in solution a small quantity of albumen and saline matter, and resembling, therefore, very dilute serum. During the first two months of gestation, the amnion and the inner surface of the chorion (which is really the reflected layer of the amnion, just as the lining of the abdominal cavity is formed by the peritoneum,) are separated by a gelatinous substance, which may perhaps be considered as representing the white of the egg in Birds, and which probably aids in the nutrition of the embryo previously to the formation of the placenta. This is absorbed during the second month; and the amnion is then found immediately beneath the chorion. In the umbilical cord, when it is completely formed, the following parts may be traced. 1. The tubular sheath afforded

by the Amnion. 2. The umbilical vesicle, with its pedicle, or omphalo-enteric duct. 3. The vasa omphalo-meseraica, or mesenteric vessels of the embryo, by which the yelk was absorbed into the body of the fœtus; these accompany the pedicle. 4. The urachus, and remains of the allantois. 5. The vasa umbilicalia, which, in the later period of gestation, constitute the chief part of the cord. These last vessels consist in Man of two arteries and one vein. The arteries are the main branches of the hypogastric; and they convey to the placenta the blood which has to be aerated and otherwise revivified by being brought into relation with that of the mother. The vein returns this to the fœtus, and discharges a part of it into the vena porta, and a part directly through the ductus venosus into the aorta.

766. A change in the type of the circulating system of the fœtus, from that at first presented by it (§ 763), takes place at a very early period. At about the 4th week, in the Human embryo, a septum begins to be formed in the ventricle; and by the end of the 8th week it is complete. The septum auriculorum is formed at a somewhat later period, and it remains incomplete during the whole of fœtal life; it is partly closed by the valvular fold covering the foramen ovale, which fold is developed during the third month. During the same period, a transformation takes place in the arrangement of the large vessels proceeding from the heart; which ends in their assumption of the form they present until the end of fœtal life; and this undergoes but a slight alteration when the plan of the circulation is changed at the moment of the first inspiration. The number of aortic arches on each side, which was five at first, soon becomes reduced in the Mammalia to three, by the obliteration of the two highest pairs. The bulbus arteriosus is subdivided, by the adhesion of its walls at opposite points, into two tubes, of which one becomes the aorta and the other the pulmonary artery; and of the three pairs of (branchial) arches, the highest being connected with the aortic trunk, contributes to the formation of the subclavian and carotid arteries; whilst of the middle pair, the arch on the right side is obliterated, the other becoming the arch of the aorta. The lowest pair arises from the pulmonary trunk, and forms the pulmonary artery on each side; that on the left side, however, goes on to join the descending aorta as before, and thus constitutes the ductus arteriosus. The following is the course of the circulation of the blood in the fœtus. The fluid brought from the placenta by the umbilical vein is partly conveyed at once to the vena cava ascendens, by means of the ductus venosus, and partly flows through the vena porta into the liver, whence it reaches the ascending cava by the hepatic vein. Having thus been transmitted through the two great depurating organs, the placenta and the fœtal liver, it is in the condition of arterial blood; but, being mixed in the vessels with that which has been returned from the trunk and lower extremities, it loses this character in some degree by the time that it arrives in the heart. In the right auricle, which it then enters, it would be also mixed with the venous blood conveyed by the descending cava; were it not that a very curious provision exists to prevent (in great degree if not entirely) any such further dilution. The Eustachian valve has been found, by the experiments of Dr. J. Reid,* to serve the purpose of directing the arterial blood which flows upwards from the ascending cava, through the foramen ovale, into the left auricle, whence it passes into the ventricle; whilst it also directs the venous blood that has been returned by the descending cava, into the right ventricle. When the ventricles contract, the arterial

* Edinb. Med. and Surg. Journal, Vol. XLIII.

blood which the left contains is propelled into the aorta, and supplies the branches that proceed to the head and upper extremities, before it undergoes any admixture; whilst the venous blood contained in the right ventricle is forced through the pulmonary artery and ductus arteriosus, into the descending aorta, mingling with the arterial current which that vessel previously conveyed, and passing thus to the trunk and lower extremities. Hence the head and superior extremities, whose development is required to be in advance of that of the lower, are supplied with blood nearly as pure as that which returns from the placenta; whilst the rest of the body receives a mixture of this with what has previously circulated through the system; and of this mixture a portion is transmitted to the placenta, to be renovated by coming into relation with the maternal fluid. At birth, the course of the current is entirely changed by its diversion into the lungs, which takes place immediately on the first inspiration. The ductus venosus and ductus arteriosus soon shrivel into ligaments; the foramen ovale becomes closed by its valve; and the circulation, which was before carried on upon the plan of that of the higher Reptiles, now becomes that of the complete Bird or Mammal. It is by no means unfrequent, however, for some arrest of development to prevent the completion of these changes; and various malformations, involving an imperfect discharge of the function, may hence result.*

767. The alimentary canal has been shown to have its origin in the yelk-sac or umbilical vesicle, being a portion pinched off (as it were) from that part of it which is just beneath the spinal column of the embryo (§ 760). At first it is merely a long narrow tube, nearly straight, and communicating with the umbilical vesicle at about the middle of its length; thus it may be regarded as composed of the union of two, an upper and a lower division. At first, neither mouth nor anus exists; but these are formed early in the second month, if not before. The tube gradually manifests a distinction into its special parts, œsophagus, stomach, small intestine, and large intestine; and the first change in its position occurs in the stomach, which, from being disposed in the line of the body, takes an oblique direction. The curves of the large and small intestines present themselves at a later period. It is at the lower part of the small intestine, near its termination in the large, that the entrance of the omphalo-enteric duct exists; and a remnant of this canal is not unfrequently preserved throughout life, in the form of a small pouch or diverticulum from that part of the intestine. The various glandular structures connected with the alimentary canal, originate in diverticula from its walls, in the manner already described in regard to the Liver (§ 660). The lungs and respiratory apparatus are formed in like manner, as diverticula from the œsophagus (§ 526).

768. The mode in which the chief organs of the Human embryo originate having been thus described, and the sufficient particulars in regard to their subsequent development having been already given under distinct heads, it is unnecessary here to add more on this very interesting but complex subject, because for practical purposes there is little or no advantage to be gained from the most perfect acquaintance with it. The most important of all the facts that have come under our view, is that which has been stated as in the highest degree probable, if not yet absolutely proved, in regard to the relative offices of the Male and Female in this hitherto mysterious process. According to the view here given, the male furnishes the germ, and the female supplies it with nutriment, during the whole period of its

* See Principles of General and Comparative Physiology, Chap. VI.

speedily forgotten, can exert such a continued influence on the nutrition of the embryo, as to occasion any personal peculiarity.* The view here stated is one which ought to have great weight, in making manifest the importance of careful management of the health of the mother, both corporeal and mental, during the important period of pregnancy; since the constitution of the offspring so much depends upon the impressions then made upon its most impressible structure.

769. It is frequently of great importance, both to the Practitioner and to the Medical Jurist, to be able to determine the age of a fœtus, from the physical characters which it presents; and the following table has been framed by Devergie† in order to facilitate such determination. It is to be remarked, however, that the absolute length and weight of the embryo are much less safe criteria than its degree of development, as indicated by the relative evolution of the several parts which make their appearance successively. Thus it is very possible for one child born at the full time to weigh less than another born at eight or even at seven months; its length, too, may be no greater; but the position of the middle point of the body will usually afford sufficient ground for the determination, since, during the two latter months of pregnancy, the increasing development of the lower extremities throws it lower down.

Embryo 3 *to* 4 *weeks.*—It has the form of a serpent;—its length from three to five lines; its head indicated by a swelling;—its caudal extremity, (in which is seen a white line, indicating the continuance of the medulla spinalis), slender, and terminating in the umbilical cord;—the mouth indicated by a cleft;—the eyes by two black points; the members begin to appear as nipple-like protuberances;—the liver occupies the whole abdomen;—the bladder is very large. The chorion is villous, but its villosities are still diffused over the whole surface.

Embryo of 6 *weeks.*—Its length from 7 to 10 lines; its weight from 40 to 75 grains; —face distinct from cranium;—aperture of nose, mouth, eyes, and ears perceptible;—head distinct from thorax;—hands and fore-arms in the middle of the length, fingers distinct;—legs and feet situated near the anus;—clavicle and maxillary bone present a point of ossification;—distinct umbilicus for attachment of cord, which at that time consists of the omphalo-meseraic vessels, of a portion of the urachus, of a part of the intestinal tube, and of filaments which represent the umbilical vessels. The placenta begins to be formed;—the chorion still separated from the amnion;—the umbilical vesicle very large.

Embryo of 2 *months.*—Length from 16 to 19 lines;—weight from 150 to 300 grains; the elbows and arms detached from the trunk;—heels and knees also isolated;—rudiments of the nose and of the lips; palpebral circle beginning to show itself;—clitoris or penis apparent; anus marked by a dark spot; rudiments of lungs, spleen, and supra-renal capsules;—cœcum placed behind the umbilicus;—digestive canal withdrawn into the abdomen;—urachus visible;—osseous points in the frontal bone and in the ribs.—Chorion commencing to touch the amnion at the point opposite the insertion of the placenta; placenta begins to assume its regular form;—umbilical vessels commence twisting.

Embryo of 3 *months.*—Length from 2 to 2½ inches;—weight from 1 oz. to 1½oz. (Troy);—head voluminous;—eyelids in contact by their free margin; membrana pupillaris visible;—mouth closed;—fingers completely separated;—inferior extremities of greater length than rudimentary tail; clitoris or penis very long;—thymus as well as supra-renal capsules present;—cœcum placed below the umbilicus;—cerebrum 5 lines, cerebellum 4 lines, medulla oblongata 1½ line, and medulla spinalis ¾ of a line, in diameter;—two ventricles of heart distinct. The decidua reflexa and decidua uterina in contact;—funis contains umbilical vessels and a little of the gelatine of Warthon;—placenta completely isolated; umbilical vesicle, allantois, and omphalo-mesenteric vessels have disappeared.

Fœtus of 4 *months.*—Length 5 to 6 inches;—weight 2½ to 3 oz.;—skin rosy, tolerably dense;—mouth very large and open;—membrana pupillaris very evident;—nails begin to appear;—genital organs and sex distinct;—cœcum placed near the

* For some valuable observations on this subject, see Montgomery on the Signs of Pregnancy.

† Médecine Légale, Vol. I. p. 495.

right kidney;—gall-bladder appearing—meconium in duodenum;—cæcal ... ble;—umbilicus placed near pubis;—ossicula auditoria ossified;—points of ossifica-tion in superior part of sacrum;—membrane forming at point of insertion of ... on uterus;—complete contact of chorion with amnion.

Fœtus of 5 *months.*—Length 6 to 7 inches;—weight 5 to 7 oz.;—volume of ... still comparatively great;—nails very distinct;—hair beginning to appear,— without sebaceous covering;—white substance in cerebellum;—heart and ... very voluminous;—cœcum situated at inferior part of right kidney;—gall-... distinct;—germs of permanent teeth;—points of ossification in pubis and ... —meconium has a yellowish-green tint, and occupies commencement of large in-testine.

Fœtus of 6 *months.*—Length 9 to 10 inches;—weight 1 lb.;—skin presents ... appearance of fibrous structure;—eyelids still agglutinated, and membrana pupillaris remains;—sacculi begin to appear in colon;—funis inserted a little above pubis;— ... of a purplish red;—hair white or silvery;—sebaceous covering begins to ... itself;—meconium in large intestine;—liver of dark red;—gall-bladder ... serous fluid destitute of bitterness;—testes near kidneys;—points of ossification ... four divisions of sternum;—middle point at lower end of sternum.

Fœtus of 7 *months.*—Length 13 to 15 inches;—weight 3 to 4 lbs.;—skin of ... thick, and fibrous;—sebaceous covering begins to appear;—nails do not yet ... extremities of fingers;—eyelids no longer adherent;—membrana pupillaris ... pearing;—a point of ossification in the astragalus;—meconium occupies ... whole of large intestine;—valvulæ conniventes beginning to appear;—cæcum ... in right iliac fossa;—left lobe of liver almost as large as right;—gall-bladder con-tains bile;—brain possesses more consistency;—testicles more distant from ... —middle point at a little below end of sternum.

Fœtus of 8 *months.*—Length 14 to 16 inches;—weight 4 or 5 lbs.;—skin ... with well-marked sebaceous envelope;—nails reach extremities of fingers;—mem-brana pupillaris becomes invisible during this month;—a point of ossification ... vertebra of sacrum;—cartilage of inferior extremity of femur presents no ... ossification;—brain has some indications of convolutions;—testicles descend ... internal ring;—middle point nearer the umbilicus than the sternum.

Fœtus of 9 *months, the full term.*—Length from 17 to 21 inches;—weight ... to 9 lbs., the average probably about 6½ lbs;—head covered with hair in greater or less quantity, of from 9 to 12 lines in length;—skin covered with sebaceous ... especially at bends of joints;—membrana pupillaris no longer exists;—external audi-tory meatus still cartilaginous;—four portions of occipital bone remain distinct;— hyoides not yet ossified;—point of ossification in the centre of cartilage at ... extremity of femur;—white and gray substances of brain become distinct;— ... descends to umbilicus;—testes have passed inguinal ring, and are frequently found in scrotum;—meconium at termination of large intestine;—middle point of body ... umbilicus, or a little below it.

770. Even at birth, there is a manifest difference in the physical condi-tions of infants of different sexes; for, in the average of a large number, there is a decided preponderance on the side of the Males, both as to the length and the height of the body. The length of the body in fifty new-born infants of each sex, as ascertained by Quetelet,* was as follows:—

	Males.	Females.	Total.
From 16 to 17 inches† (French)	2	4	6
" 17 to 18 "	8	19	27
" 18 to 19 "	28	18	46
" 19 to 20 "	12	8	20
" 20 to 21 "	0	1	1

From these observations, the mean and the extremes of the lengths of the male and female respectively, were calculated to be,—

	Males.		Females.	
Minimum .	16 inches,	2 lines	16 inches,	2 lines
Mean . .	18	6	18	1¼
Maximum .	19	8	20	6

* Sur L'Homme, Tom. II. p. 8.

† The French inch is about one-fifteenth more than the English.

Notwithstanding that the maximum is here on the side of the female (this being an accidental result, which would probably have been otherwise, had a larger number been examined), the average shows a difference of 4½ lines in favour of the male.—The inequality in the weight of the two is even more remarkable; the observations of M. Quetelet* were made upon 63 male and 56 female infants.

Infants weighing from	Males.	Females.	Total.
1 to 1½ kilog.† . . .	0	1	1
1½ to 2	0	1	1
2 to 2½	3	7	10
2½ to 3	13	14	27
3 to 3½	28	23	51
3½ to 4	14	7	21
4 to 4½	5	3	8

The extremes and means were as follows:—

	Males.	Females.
Minimum	2·34 kilog.	1·12
Mean	3·20	2·91
Maximum	4·50	4·25

The average weight of infants of both sexes, as determined by these inquiries, is 3.05 kilog. or 6.7 lbs.; and this corresponds almost exactly with the statement of Chaussier, whose observations were made upon more than 20,000 infants. The mean obtained by him, without reference to distinction of sex, was 6.75 lbs.; the maximum being 11·3 lbs., and the minimum 3·2 lbs.‡ The average in this country is probably rather higher; according to Dr. Joseph Clarke,§ whose inquiries were made on 60 males and 60 females, the average of male children is 7½ lbs.; and that of females 6¾ lbs. He adds that children which at the full time weigh less than 5 lbs. rarely thrive; being generally feeble in their actions, and dying within a short time. Several instances are on record, of infants whose weight at birth exceeded 15 lbs. It appears that healthy females, living in the country, and engaged in active but not over-fatiguing occupations, have generally the largest children; and this is what might be expected *a priori*, from the superior activity of their nutritive functions.

771. Notwithstanding that, in any ordinary population, there is a decided preponderance in the number of the females, the number of male births is considerably greater than that of females. Taking the average of the whole of Europe, the proportion is about 106 males to 100 females. It is curious, however, that this proportion is considerably different for legitimate and for illegitimate births; the average of the latter being only 102½ to 100, in the places where that of the former was 105¾ to 100. This is probably to be accounted for by the fact, which is one of the most remarkable contributions that have yet been made by Statistics in Physiology, that the sex of the offspring is influenced by the relative ages of the parents. The following table expresses the average results obtained by M. Hofacker‖ in Germany, and by

* Op. cit. Tom. II. p. 35.

† The kilogramme is equal to 2¼ lbs. avoirdupois.

‡ These numbers have been erroneously stated in many physiological works, owing to the difference between the French and English pound not having been allowed for.

§ Philosophical Transactions, Vol. LXXVI.

‖ Annales d'Hygiène, Oct. 1829.

Mr. Sadler* in Britain; between which it will be seen that there is a manifest correspondence, although both were drawn from a too limited series of observations. The numbers indicate the proportion of male births to 100 females, under the several conditions mentioned in the first column.

	Hofacker.		Sadler.
Father younger than Mother	90·6	Father younger than Mother	86·5
Father and Mother of equal age	90·0	Father and Mother of equal age	94·8
Father older by 1 to 6 years	103·4	Father older by 1 to 6 years	103·7
. . 6 to 9	124·7	. . 6 to 11	126·7
. . 9 to 18	143·7	. . 11 to 16	147·7
. . 18 and more	200·0	. . 16 and more	163·2

From this it appears that the more advanced age of the male parent has a very decided influence in occasioning a preponderance in the number of male infants; and, as the state of society generally involves a condition of this kind in regard to marriages, whilst in the case of illegitimate children the same does not hold good, the difference in the proportional number of male births is accounted for. We are not likely to obtain data equally satisfactory in regard to the influence of more advanced age on the part of the female parent; as a difference of 10 or 15 years on that side is not so common. If it exist to the same extent, it is probable that the same law would be found to prevail in regard to female children born under such circumstances, as has been stated with respect to the male;—namely, that the mortality is greater during embryonic life and early infancy, so that the preponderance is reduced.

772. There appears to be, from the first, a difference in the *viability* of male and female children; for, out of the total number born dead, there are 3 males to 2 females; this proportion gradually lessens, however, during early infancy; being about 4 to 3 during the first two months, and about 4 to 5 during the next three months, after which time the deaths are nearly in proportion to the numbers of the two sexes respectively, until the age of puberty. The viability of the two sexes continues to increase during childhood; and attains its maximum between the 13th and 14th years. For a short time after this epoch has been passed, the rate of mortality is higher in females than in males; but from about the age of 18 until 28, the mortality is much greater in males; being at its maximum at 25, when it is only half what it is at puberty. This fact is a very striking one; and shows most forcibly that the indulgence of the passions not only weakens the health, but in a great number of instances is the cause of a very premature death. From the age of 28 to that of 50, the mortality is greater, and the viability less, on the side of the female; this is what would be anticipated from the increased risk to which she is liable during the parturient period. After the age of 50, the mortality is nearly the same for both. These facts have been expressed by Quetelet in a form which brings them prominently before the eye (Fig. 94). The relative viability at different ages is represented by a curved line, the elevation of which indicates its degree, at the respective periods marked along the base line. The dotted line which follows a different curve, represents the viability of the female. Starting from *a*, the period of birth, we arrive at the maximum of viability for both at *b*; from this point, the female curve steadily descends towards *n*, at first very rapidly, but afterwards more gradually; whilst the male curve does not quite descend so soon, but afterwards falls much lower, its minimum being *c*, which corresponds with the age of 25

* Law of Population, Vol. II. p. 343.

Fig. 94.

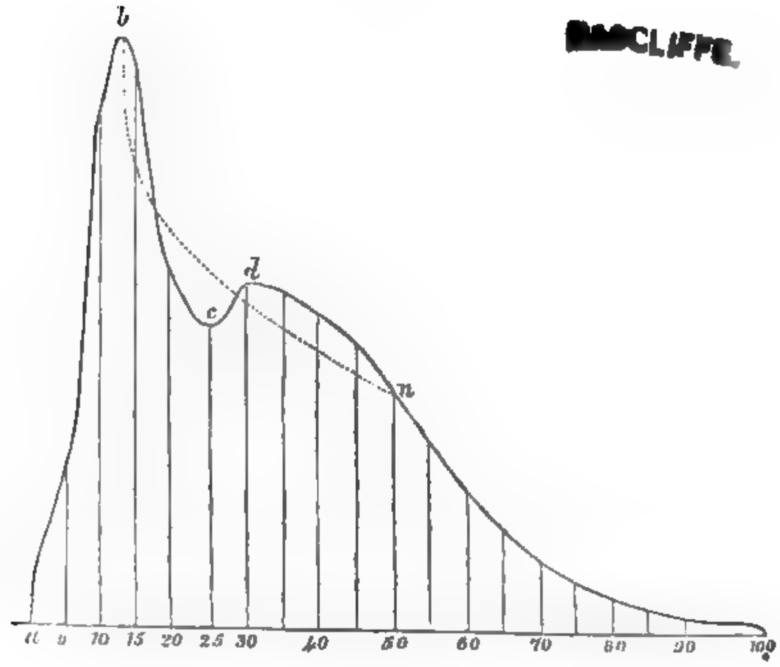
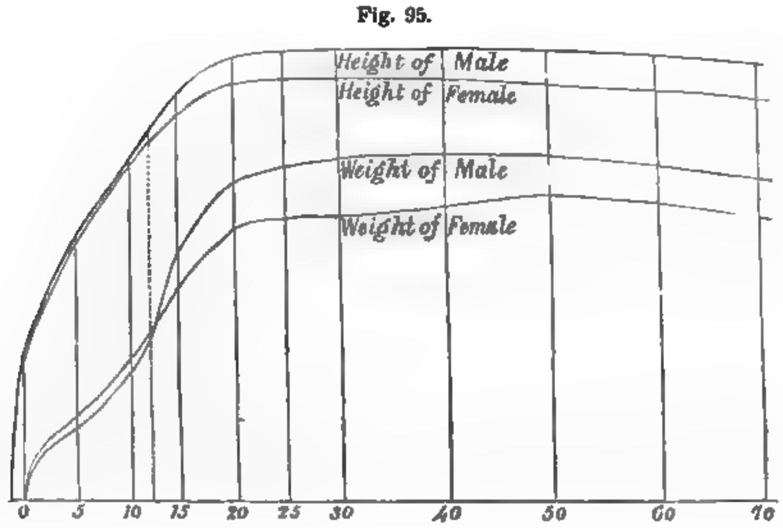

b
c
d
n
0 5 10 15 20 25 30 40 50 60 70 80 90 100

Fig. 95.


Height of Male
Height of Female
Weight of Male
Weight of Female
0 5 10 15 20 25 30 40 50 60 70

years. It afterwards ascends to *d*, which is the maximum of viability subsequently to the age of puberty; this point is attained at the age of 30 years, from which period, up to 50, the probability of life is greater in the male than the female. In the decline of life there seems little difference for the two sexes.—Similar diagrams have been constructed by Quetelet, to indicate the relative heights and weights of the two sexes. In regard to height it may be observed, that the increase is most rapid in the first year, and that it afterwards diminishes gradually; between the ages of 5 and 16 years, the annual increase is very regular. The difference between the height of the male and female, which has been already stated to present itself at birth, continues to increase during infancy and youth; it is not very decided, however, until about the 15th year, after which the growth of the female proceeds at a much diminished rate, whilst that of the male continues in nearly the same degree, until about the age of 19 years. It appears, then, that the female comes to her full development in regard to height, earlier than does the male. It appears probable, from the observations of Quetelet, that the full height of the male is not generally attained until the age of 25 years; at about the age of 50, both male and female undergo a diminution of their stature, which continues during the latter part of life. The proportional weight of the two sexes at different periods corresponds pretty closely with their height. Starting from birth, the predominance then exhibited by the male gradually increases during the first few years; but towards the period of puberty, the proportional weight of the female increases; and at the age of 12 years, there is no difference between the two sexes in this respect. The weight of the male, however, then increases much more rapidly than that of the female, especially between the ages of 15 and 20 years; after the latter period, there is no considerable increase on the side of the male, though his maximum is not attained until the age of 40; and there is an absolute diminution on the part of the female, whose weight remains less during nearly the whole period of child-bearing. After the termination of the parturient period, the weight of the female again undergoes an increase, and its maximum is attained about 50. In old age, the weight of both sexes undergoes a diminution in nearly the same degree. The average weights of the male and female that have attained their full development are twenty times those of the new-born infant of the two sexes respectively. The height, on the other hand, is about 3¼ times as much.

773. The chief differences in the constitution of the two sexes manifest themselves during the period, when the generative function of each is in the greatest vigour. Many of these distinctions have been already alluded to; but there are others of too great importance to be overlooked; and these chiefly relate to the Nervous System and its functions. There is no obvious structural difference in the Nervous System of the two sexes (putting aside the local peculiarities of its distribution to the organs of generation), save the inferior size of the cerebral hemispheres in the Female. This difference, which is not observed in other parts of the encephalon, is readily accounted for on the principles formerly stated, when we compare the psychical character of Woman with that of Man. For there can be no doubt that—putting aside the exceptional cases which now and then occur—the intellectual powers of Woman are inferior to those of Man: although her perceptive faculties are more acute, her capability of sustained mental exertion is much less, and though her views are often peculiarly distinguished by clearness and decision, they are generally deficient in that comprehensiveness which is necessary for their stability. With less of the *volitional* powers than Man possesses, she has the *emotional* and *instinctive* in a much stronger degree. The emotions

therefore predominate; and more frequently become the leading springs of action, than they are in Man. By their direct influence upon the bodily frame, they produce changes in the organic functions, which far surpass in degree any thing of the same kind that we ordinarily witness in Man; and they thus not unfrequently occasion symptoms of an anomalous kind, which are very perplexing to the practitioner, but very interesting to the Physiological observer. But they also act as powerful motives to the Will; and, when strongly called forth, produce a degree of vigour and determination, which is very surprising to those who have usually seen the individual under a different aspect. But this vigour, being due to the strong excitement of the feelings, and not to any inherent strength of intellect, is only sustained during the persistence of the motive, and fails as soon as it subsides. The feelings of Woman, being frequently called forth by the occurrences she witnesses around her, are naturally more disinterested than those of Man; *his* energy is more concentrated upon one object; and to this his intellect is directed, with an earnestness that too frequently either blunts his feelings, or carries them along in the same channel, thus rendering them selfish. The intuitive powers of Woman are certainly greater than those of Man. Her perceptions are more acute, her apprehension quicker; and she has a remarkable power of interpreting the feelings of others, which gives to her, not only a much more ready sympathy, but that power of guiding her actions so as to be in accordance with them, which we call *tact*. This tact bears a close correspondence with the *adaptiveness* to particular ends, which we see in instinctive actions. In regard to the inferior development of her intellectual powers, therefore, and in the predominance of the instinctive, Woman must be considered as ranking below Man; but in the superior purity and elevation of her feelings, she is as highly raised above him. Her whole character, psychical as well as corporeal, is beautifully adapted to supply what is deficient in Man; and to elevate and refine those powers which might otherwise be directed to low and selfish objects.

ADDENDA AND CORRIGENDA.

§ 487. At page 356, line 2, for *mitral* read *tricuspid*.

§ 588. At page 431, *note*, line 4, for *forms* read *form*.

§ 298. So completely does the power of producing convulsive movements appear limited to the Spinal system of nerves (no mechanical irritation of the cerebral substance being effectual in exciting such movements, § 286), that, where convulsions present themselves during Diseases of the Nervous System which appear to be confined to the Brain, we may infer that the Spinal system is in some {degree} involved. Dr. M. Hall has recently pointed out a curious source of convulsive affections which has been hitherto unsuspected. In some of his experiments on the brain, he noticed that, if the dura mater be pinched or lacerated, peculiar spasmodic movements are excited. This is probably due to the branches of the fifth pair which are distributed through it, and which serve as *excitors* in producing reflex action. (See Medico-Chirurgical Transactions, Vol. xxiv. p. 122.)

§ 534. Dr. Andral and M. Gavarret have been for some time engaged in a very extensive series of researches on the quantity of carbonic acid exhaled from the lungs of the human species. The tendency of this investigation will be to advance considerably our knowledge of the respiratory function, both physiologically and pathologically. Their first object has been to ascertain the modifying influence of *age*, *sex*, and constitution. To determine this, their observations have been made under circumstances as uniform as possible; the subjects of them having been in good health, and in similar condition as regards food, muscular expenditure, moral state, interval subsequently to the last meal, and hour of the day. Each experiment was repeated several times on the same subjects, and the accordance be-

tween the results has been as great as could be desired in physiological researches. The apparatus employed was so devised, as to enable the respirations to be freely performed; no portion of the expired air was again inspired; and the greatest care was taken to analyze the expired air with accuracy. The observations were continued, in each case, from about 8 to 13 minutes, until about 130 *litres* of gas were collected; and from these, the amount of carbonic acid thrown off per hour is calculated in terms of the quantity of solid carbon it contains. This is done, however, for the sake of comparison only, as it is not supposed by the authors that the means are thus afforded of estimating the whole quantity thrown off in 24 hours,—a question of which they reserve the consideration for the present. The following are the general results already obtained by them.

1. The quantity of carbonic acid exhaled by the lungs in a given time, varies according to the age, sex, and constitution of the subjects.

2. In both man and woman, the quantity undergoes modification according to the ages of the subjects experimented on, quite independently of their weights.

3. In all periods of life, comprised between 8 years and the most advanced old age, man and woman are distinguished by the difference in the amount of carbonic acid exhaled from their lungs in a given time. All other things being equal, man exhales a much larger quantity than woman. This difference is particularly well marked between the ages of 16 and 40 years, during which period the quantity of carbonic acid exhaled is nearly twice as much in man as in woman.

4. In man, the quantity of carbonic acid exhaled, continues to increase regularly from 8 to 30 years of age, and a remarkable increase takes place at the period of puberty. After 30 years, the exhalation of carbonic acid begins to decrease; and this decrease continues, becoming more and more marked, as the individual approaches nearer to extreme old age; so that, at this period, it returns to the standard at which it was about the age of 10 years.

5. In woman, the exhalation of carbonic acid augments according to the same laws as in man, up to the period of puberty; but at that epoch, the increase suddenly ceases; and the amount continues at this low standard, with little variation, as long as the catamenia make their regular appearance. But as soon as they cease, the exhalation of carbonic acid by the lungs undergoes a considerable increase; after which it decreases, as in man, in proportion as the age advances.

6. During the period of gestation, the amount of carbonic acid exhaled is temporarily raised to the standard which it attains after the cessation of the catamenia.

7. In both sexes, and at all ages, the quantity of carbonic acid exhaled by the lungs, is greater in proportion to the strength of the constitution, and the development of the muscular system.

The numerical results contained in the memoir itself, are collected in the following table, which expresses the quantity of solid carbon calculated to be exhaled in one hour. The gramme is equal to about 15½ grains.

Male.	Female.	
8 years ... 5 grammes.	8 years ...... 5 grammes.	The same standard continues in women during the whole of the menstrual period; but if the catamenia be temporarily suppressed, or pregnancy occur, it rises to the standard it attains after their entire cessation, namely 8·4 grammes.
15 .... 8·7	12–38 .... 6·4	
16 .... 10·8	38–50 .... 8·4	
18–20 ..... 11·4	50–60 .... 7·3	
20–30 ..... 12·2	60–80 .... 6·8	
30–40 ..... 12·2	82 .... 6·0	
40–60 ..... 10·1		
60–80 ..... 9·2		
102 ...... 5·9		

These numbers express the *averages;* the maximum amount is often considerably greater. In a young man of athletic system, and sound constitution, the quantity of carbonic acid exhaled in an hour was 14.1 grammes; a man of 60, equally vigorous for his age, threw off 13·6 grammes; and a man of 63 years, 12·4 grammes. An old man of 92 years, who preserved a remarkable degree of energy, and who had possessed an uncommon degree of vigour in his youth, was found to throw off 8·8 grammes per hour; whilst the same amount appeared to be the usual standard in a man of 45 years of age, who, unlike the preceding, had a feeble system, though in equally good health. The question how far these variations are connected with differences in the capacity of the chest, and in the number of respiratory movements, will be discussed in a future memoir.—*Annales des Sciences Naturelles.* Fevrier, 1843, p. 287; and *Brit. & For. Med. Rev.* No. XXXI. July, 1843.—M. C.}

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